HUMAN FACTORS IN DIVING

By

Michael A. Blumenberg

Marine Technology & Management Group

University of California, Berkeley

Supervised by

Professor Robert Bea

December 1996

ENCLOSURE (3)

ABSTRACT

HUMAN FACTORS IN DIVING

Dive safety is primarily a function of four factors: the environment, equipment, individual diver performance and dive team performance. The water is a harsh and alien environment which can impose severe physical and psychological stress on a diver. The remaining factors must be controlled and coordinated so the diver can overcome the stresses imposed by the underwater environment and work safely. Diving equipment is crucial because it provides life support to the diver, but the majority of dive accidents are caused by individual diver panic and an associated degradation of the individual diver's performance. This paper investigates the factors which influence human performance and behavior, and focuses on divers working underwater. Recommendations are offered on how to improve dive safety through knowledge and awareness of human factors.

OUTLINE

HUMAN FACTORS IN DIVING

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

The importance of human factors in diving.

Human error is inevitable (Reason, 1990). Nobody's perfect. Everyone makes mistakes. Fortunately, most of our errors are minor and do not cause significant harm. Unfortunately, modern technology and hazardous environments often magnify the consequences of human errors and the results can be catastrophic. Human error in a high tech environment has been the primary cause of the modern era's most severe accidents. Consider the Three Mile Island nuclear power plant disaster, where a series of operator errors allowed a complex and highly technical system to run amuck, or the Exxon Valdez, a good ship that ran aground due to human error. Examples of human error leading to accidents are almost limitless (Perrow, 1984).

The study of human factors seeks to improve safety by reducing the frequency of human error and mitigating the consequences of human error when it occurs. Human behavior is far too complicated and unpredictable to ever eliminate human error, but by understanding *how* and *why* humans make errors we can dramatically improve safety. Human error is the direct cause of 60% to 80% of all accidents (Perrow, 1984). In the maritime industry, approximately 80% of all accidents are attributable to human error (Bea,1995). Consequently, many of the major maritime organizations, such as the U.S. Coast Guard, American Bureau of Shipping, and the Mobil Shipping & Transportation Company, are placing greater emphasis on human factors (American Bureau of Shipping, 1996). The U.S. Coast Guard recently launched it's Prevention Through People program that "recognizes the human element as occupying a critical role in maritime safety" (Card, 1996).

In diving, human error can have catastrophic consequences. A recent study from the University of Wisconsin indicates that over half of all divers surveyed experienced panic underwater sometime during their diving career (Morgan, 1995). Morgan's findings were recently corroborated by an independent survey of recreational divers that indicated 65 percent of divers have panicked under water (Staff, 1996). Panic can lead to errors in a diver's judgment or performance, resulting in an accident. Since

a diver is immersed in a harsh environment and relies on technical equipment for life support, the consequences of a dive accident can be severe. Experts agree that human error and panic are the leading causes of dive accidents and fatalities (Brown, 1982; Elliott, 1984; Bachrach & Egstrom, 1987; Morgan, 1995, 1987; Shelanski, 1996; Vorosmarti, 1987).

2. OVERVIEW OF HUMAN FACTORS

Safety is a direct function of human performance, and can be promoted by reducing the frequency and impact of human error. To combat human error, it is necessary to understand how and why people commit errors. The study of human factors (HF) categorizes how errors occur and defines influences on humans that explain why errors occur. This paper focuses on human factors in diving and investigates how and why divers commit errors and panic. Human factors are defined as the complex system of influences which shape human behavior, and the resultant effects that human performance exerts on a system or process. The goal of this paper is the promotion of dive safety through increased awareness and accounting of human factors in diving. This section introduces the concept of human factors, describes how and why errors occur, how accidents evolve from errors, and strategies to combat error.

Human Error

Human error can be defined as an individual's deviation from acceptable or desirable practice which culminates in undesirable or unexpected results (Bea, 1994). An error can prevent a plan from achieving its desired outcome.

Errors come in many forms, so it is helpful to categorize *how* errors occur. Several researchers have proposed categories for human error. Reason (1996, 1990) categorizes *how* errors occur by studying what causes plans to fail. If the plan is good but execution is not, then the failure is due to *slips, lapses, trips* or *fumbles.* If the plan itself is faulty, then the failure is due to a *mistake.* If established procedures or regulations are purposefully ignored, then the mistake can be further defined as a *violation.*

Reason's (1996) error categories are related to three levels of human performance: skill-based, rule-based and knowledge-based. The key features of these performance levels are summarized below:

- At the *skill-based performance level*, people carry out routine, highly-practiced tasks in a largely automatic fashion, except for occasional conscious progress checks. Driving a car is a common example.
- If these automatic responses must be modified, then people switch to the *rule-based performance level*. It is called 'rule-based' because people apply memorized performance patterns or rules that state 'If (this situation), then do (these actions).' The situation is often one that has been encountered before, and perceptions of the situation are used to select an appropriate pre-patterned solution from memory. Potential solutions are developed through training, experience or education and are stored in memory. Solutions are selected automatically, but conscious thought is used to verify that the solution is appropriate. An example of rule-based performance could be driving a rental car where the controls are in a different location, but the basic operating rules still apply.
- The *knowledge-based performance level* is reached only when pre-patterned solutions from memory fail to match the given situation. Knowledge-based performance is slow, laborious and highly error-prone. Given good resources (information, tools, time, etc.), people can often develop good solutions. In the real world, however, people are often faced with limited resources, especially during emergencies, and well-reasoned responses are too often replaced with inappropriate and unsuccessful reactions. Continuing the rental car example, knowledge-based performance is necessary to navigate through a new city.

Three error *mechanisms* can now be defined. This is an important step because it correlates the error *categories* (e.g. , slips) with human performance levels (Reason, 1996).

- *Skill-based slips, lapses, trips* and *fumbles*, where the plan is good but execution is not. For example, a fender-bender may be the result of a driver's lapse in attention.
- *Rule-based mistakes* where someone misapplies a good rule, applies a bad rule, or fails to apply a good rule. (*Violations* are a sub-category of mistakes that are

elaborated below.) For example, a fender-bender which results from unsuccessfully speeding through a yellow light.

- *Knowledge-based mistakes* where an individual makes a cognitive error in an attempt to think through a new problem or situation. For example, getting lost while driving in a new city.

Violations are a special category of mistakes where somebody fails to apply a good rule, or deviates from acceptable or desirable practice. Reason (1996) identifies four categories of violations:

- Routine violations, which involve cutting corners, or taking short cuts.
- Violations 'for kicks', where rules are broken to prove machismo or to alleviate boredom.
- Necessary violations, when the rules prevent people from performing their jobs.
- Exceptional violations, which usually are the result of extreme emotions.

The tendency to violate rules is a function of age and gender: Most young men tend to violate rules while most older women do not. It is important to recognize that while rule violations are a function of age and gender, error proneness is not. Men and women, old or young, do not show a marked differences in error proneness (Reason, 1996).

Reason's error mechanisms explain the psychological basis that causes errors, but these mechanisms are not readily observable. Bea (1996) offers a breakdown of human error categories which emphasize observable behavior. This is important because errors must be recognized and acknowledged before they can be corrected. Bea's categories are also useful during accident investigations. Many investigations conclude that the accident was simply caused by "human error" ("Human error", 1996). It is necessary to define error further as an observable behavior which can be acknowledged, and then reduced or eliminated. This is an essential step in accident investigations if we are to learn from past accidents. Bea's categories of human error are listed in Table 1.

Mistakes	Ignorance	Planning	Preparation
Slips	Communications	Selection	Training
Violations		Limitations	Impairment

Table 1: Categories of Human Errors (from Bea, 1996)

Error categories define *how* an accident occurred and can help prevent future accidents under similar circumstances. Accident *prevention*, however, demands that we understand both how errors occur and *why*. Why do people slip, lapse, fumble, make mistakes, and violate rules? Why do people commit errors? Understanding why errors occur will allow proactive identification of conditions that cause errors and have the potential to cause accidents.

Human Factors

The study of human factors (HF) analyzes the complex system of influences which shape human behavior and explains *why* errors occur. Figure 1 illustrates the factors that are present in every system (e.g., a ship at sea, a hospital operating room, or a dive team). These factors influence the system's performance. The individual is at the core of the model because every system is designed, programmed, operated and repaired by people (Card, 1996). Moreover, people are responsible for the majority of accidents, and they are the key to accident prevention (Bea, 1996). The factors surrounding the individual influence his or her behavior and performance, both positively and negatively. The interactions between the factors, represented by the lines between boxes, also significantly influences the individual and each of the other factors. Each factor is defined below.

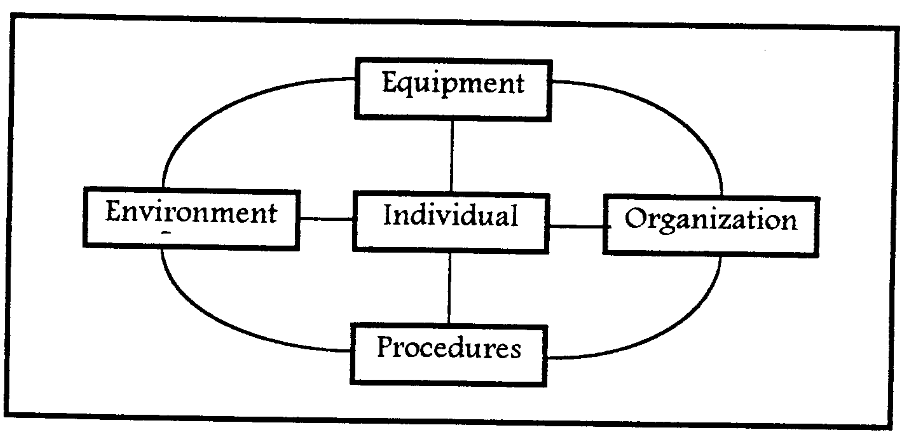

Figure 1: Factors and interfaces that influence system performance (from Bea, 1995)

- Individual: Cognitive scientists who have studied human behavior have determined that an individual's performance is constantly influenced by a variety of internal and external factors, called Performance Shaping Factors (PSF)[1] (Boniface, 1996). These factors can either promote individual effectiveness or deter it, and thus increase or decrease the probability of human error (Boniface, 1996). These individual performance shaping factors must be differentiated from the system factors shown in figure 1. System factors influence the performance of the entire system, which the individual is a part of. That individual is in turn affected by the performance shaping factors shown in table 2. The factors shown in figure 1 are the dominant shaping factors. Additional general categories of PSF's are listed in table 2. It is crucial that anyone concerned with safety recognizes that human performance has limits, and that it is a complex and dynamic function of these shaping factors.

Change	Experience	Communication	Training
Motivation	Workload	Impairment	Education

Table 2: Some Categories of Performance Shaping Factors (from Boniface, 1996; Reason, 1990)

- Organizational Factors: Organizational factors reflect the organization's structure, procedures and culture. Many researchers believe that the organizational factors are the dominant influences on individual performance (Bea, 1996).
- Equipment Factors: Equipment design, complexity and automation often influence the occurrence of human errors and their impact. Simple equipment is less likely to generate operator errors, while robust equipment can withstand the consequences of errors. Ergonomics and human factors engineering promote effective human-equipment interfaces.
- Environment: The work environment has a direct physical and psychological impact on workers. The work place may be hot or cold, loud or quiet, neat or

[1] For further discussion of performance shaping factors, the reader is referred to Boniface and Reason.

cluttered, and so on. These physical factors affect an individual's ability to think and perform effectively.

- Procedural Factors: Rules, regulations, directions and other forms of procedures guide daily activities. Well-reasoned procedures can promote efficiency and effectiveness, while complex or ambiguous procedures are often a source of human error.
- Interactions between factors: Each factor effects every other. For example, cold weather may degrade equipment performance and mandate a change to the planned work procedure. These interactions are often complex, unpredictable and obscure. Serious accidents can develop before complex interactions can be identified and corrected (Perrow, 1984).

System performance is a function of all of the above factors, however, it is the human factor which has the dominant effect on system reliability (Bea, 1996). Therefore, it is important to understand how individual performance is affected by performance shaping factors (table 2).

Stress

The concept of *stress* explains how human performance reacts to the influences of performance shaping factors and why errors often occur. A noted authority on stress, Hans Selye, states that stress is an inevitable human condition which, if mismanaged, can result in distress (Brief, Schuler & Van Sell, 1981). Stress is "the result of an imbalance between the demands placed upon an individual and the capacity of that individual to respond to the demands" (McGrath, 1970). This imbalance compels an individual to respond or take action in order to change the situation and reduce the stress (Potter & Perry, 1989). The stress response, or coping, process is modeled in figure 2.

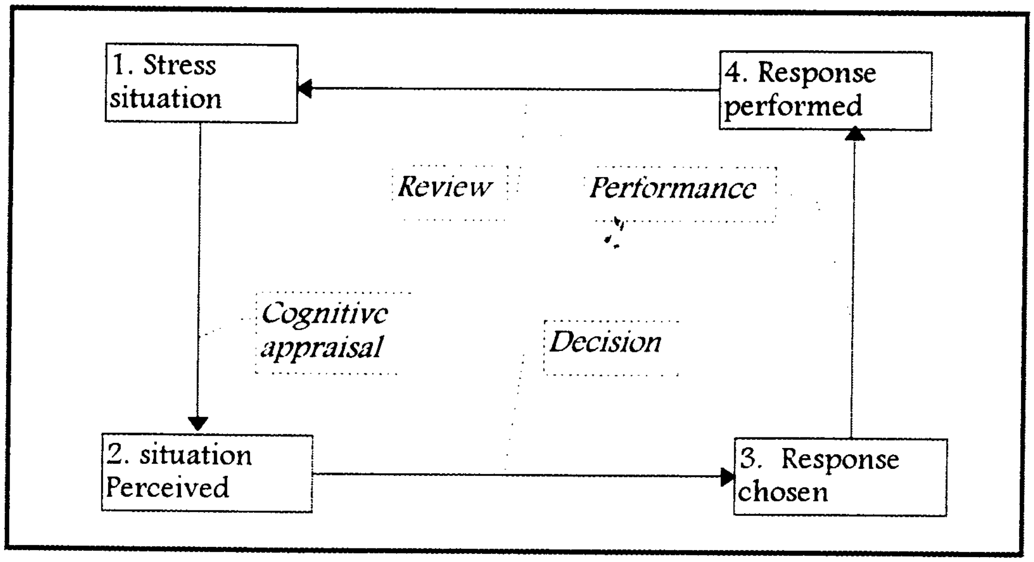

Figure 2: Stress response process model (From Potter & Perry, 1989)[2]

The stress response model is a four-stage process linked by four individual actions: cognitive appraisal, decision, performance, and review. The stress response process is initiated by stimuli, called *stressors,* which may be any or all of the factors discussed previously. The stressor creates a stress situation, which is the model's first stage. The individual cognitively appraises the situation, comparing it to previous experiences with similar stressors. Thus the individual is operating on Reason's rule-based or knowledge-based performance level. The perceived stress will vary dramatically between individuals because perception of stressors is a learned behavior. Infants learn to judge whether situations are stressful by modeling parents, then peers and society.

Perception of stress is also information sensitive, so the perceived stress level can often be reduced by reducing uncertainty, often through education and experience. Thus, a stressor which one individual perceives as a 'threat', may be perceived as a 'challenge' by someone else. Both perceptions evoke a response, but indicate dramatically different levels of stress tolerance and ability to cope with the stress situation. Additionally, the perception of stress reflects the circumstances. For example, most divers would view the appearance of a shark underwater as a stressor. If the goal of the dive, however, is to view sharks, then the sighting of a shark would not be a

[2] Adapted from Stress and work: A managerial perspective, by John M. Ivancevich and Michael T. Matteson. Glenview, Ill.

stressor (Bachrach, 1987). Thus, for a given situation, every individual will perceive differing levels of stress, possibly even no stress (Potter & Perry, 1989).

Individual differences in stress perception can be evaluated using Spielberger's (1969) "State-Trait Anxiety Inventory (STAI)". STAI is a tool for measuring anxiety, or the feeling of uneasiness caused by stress, in adults. The STAI differentiates between the temporary condition of "state anxiety" and the more general and long-standing quality of "trait anxiety". State anxiety is a function of immediate stressors acting upon an individual, and is most sensitive to information. Trait anxiety, on the other hand, reflects each individual's personality and is relatively constant. STAI has proven useful for identifying persons with high levels of neurotic anxiety and for screening such individuals from high stress occupations (Mind Garden, 1996)

If stress is perceived, then the individual has entered the model's second stage. Now the individual must decide how to respond or cope with the stressor. The individual must scan the situation, interrogate one's memory, evaluate available options, then choose the best course of action to respond. The individual enters the stress response model's third stage when a response is chosen.

Performing the chosen response transitions to the model's fourth stage. It is important to recognize that the individual's ability to perform is affected by the stress situation. The model's final step is a conscious review of how the response affected the stress situation. If the response reduced the perceived stress to a tolerable level, then the response was successful and the process stops. If the level of stress remains high, the individual moves through the stress response process again and attempts a new response. This process can repeat indefinitely until the stress is reduced to acceptable levels, or excessive stress levels truncate the process and prevent further coping.

Performance under stress

It is important to recognize that individual performance is a function of the perceived stress level, as shown in figure 3. If stressors are absent, people may be careless and commit careless errors that result in poor performance. On the other hand, strong stressors can overwhelm capacity, causing other errors and associated poor performance. Peak performance occurs in a zone of optimal stress when the stress

demands are slightly less than an individual's capacity to respond (Bachrach, 1987). This zone varies for each individual and every situation. Peak performance cannot be maintained continuously because both demand and capacity constantly fluctuate. Note, however, that performance can be improved through personnel selection (Flin & Slaven, 1995) and training (Bachrach, 1987).

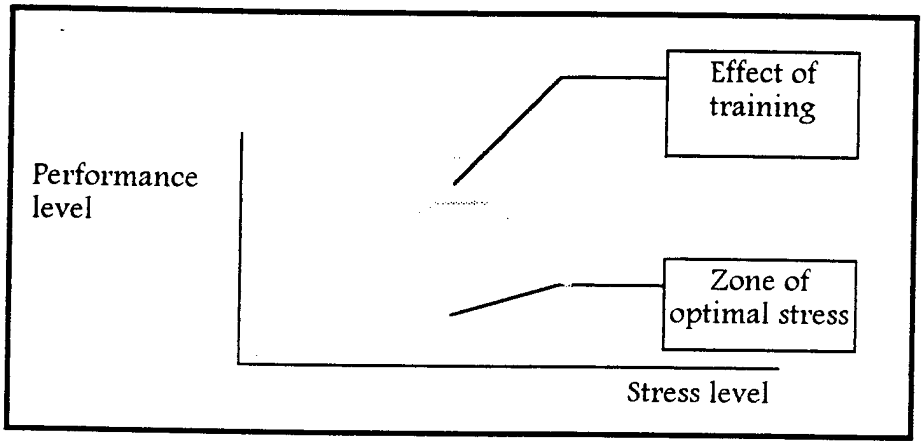

Figure 3: Effects of stress on Human Performance (from Bea, 1996)

Training

Training has several benefits. As shown in figure 3, training can increase an individual's performance level for a given stress level. Training can also improve coping skills by developing response rules or templates to given stress situations. These templates are patterns of action which have been learned experientially and can be matched to future stress situation. These templates are utilized when an individual operates on Reason's rule-based performance level. If a suitable template matches a given situation, then the individual does not have to go through a long and error prone cognitive process. Thus templates can reduce stress and improve coping skills.

The goal of training should be to increase an individual's ability to continue the normal coping process when presented with unforeseen circumstances (Bachrach, 1987). The danger of training and templates is over-reliance. Every stress situation is unique and therefore no template will match perfectly. The individual must retain some conscious ability to check the template and adapt it to the specific situation. Training, therefore, should emphasize continuous information processing and decision making under stress (Roberts, 1995).

Panic

It is important that an individual maintains the ability to process information and make decisions while under stress. An individual sense of control and competence over or within a stress situation is crucial. An out-of-control, over-stressed individual will tend to truncate the coping process and become indecisive, losing the ability to analyze and act. As the stress situation overcomes the individual's ability to cope, panic sets in. Panic establishes a barrier in the stress response model, as shown in figure 4, that prevents the decision process. A lack of action or continuation of an inappropriate ongoing action may lead to errors and accidents.

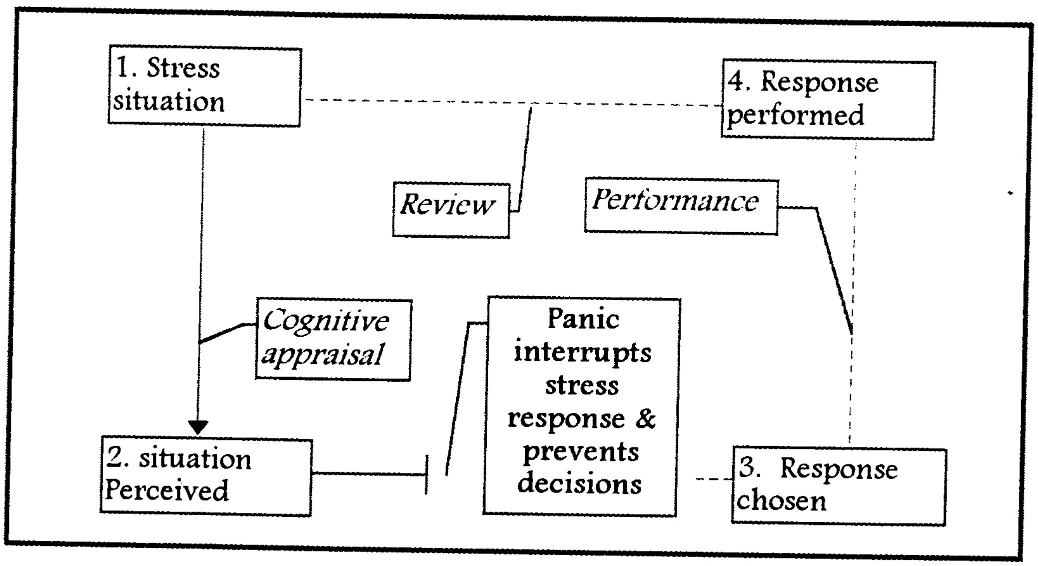

Figure 4: Panic disrupts the stress response process (From Potter & Perry, 1989)[3]

From errors to accidents...

Figure 5 illustrates the process which creates errors and can culminate in an accident. In this study, an *accident* will be defined as personnel injury, occupational illness, death, or material loss or damage (This definition is based upon the Navy's definition of a mishap. See OPNAVINST 5100.19C). Conversely, a *near accident* will be defined as an event which had the potential to cause personnel injury, occupational illness, death, or material loss or damage, but did not due to some corrective action.

[3] Adapted from Stress and work: A managerial perspective, by John M. Ivancevich and Michael T. Matteson. Glenview, Ill.

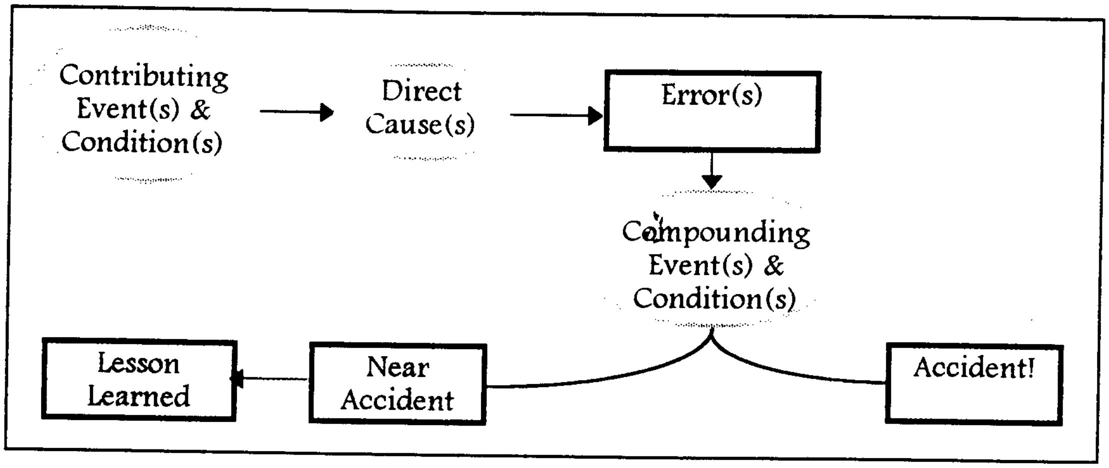

Figure 5: Direct, contributing and compounding events lead to accidents (modified from Bea, 1996)

There are three critical steps in the evolution of an error into an accident: a direct cause; contributing event(s) and condition(s); and compounding event(s) and condition(s). The *direct cause* is the action or lack of action which immediately precedes the error. An example of a direct cause could be falling asleep while driving an automobile. *Contributing events and conditions* set the stage, or plant the seeds, for future direct causes of errors. To continue the example, a contributing event which caused the driver to fall asleep was his all-night study session cramming for a final exam. Once the error has occurred, *compounding events and conditions* can either diffuse the error or exacerbate it. Again, continuing with the example, a compounding effect could be the noise created by raised lane markers which helped to wake the driver and prevent an accident. Conversely, we could imagine several conditions such as a narrow road or soft shoulder which could magnify the potential negative consequences of the error. The factors identified at the beginning of this section in figure 1 (equipment, procedures, organization, environment, individual, and interactions) are the sources of contributing and compounding events and conditions.

It should be noted that near accidents can be learning experiences which help identify sources of error and eliminate contributing and compounding conditions. According to Gary Beyerstein (1995), the Safety Manager at SubSea International, safety studies estimate a million shortcuts precede every fatality. The fatality is the tip of the accident pyramid shown in figure 6. The base of the pyramid is comprised of the shortcuts, and

in between are escalating levels of near-accidents which could (but too often do not) serve as lessons learned.

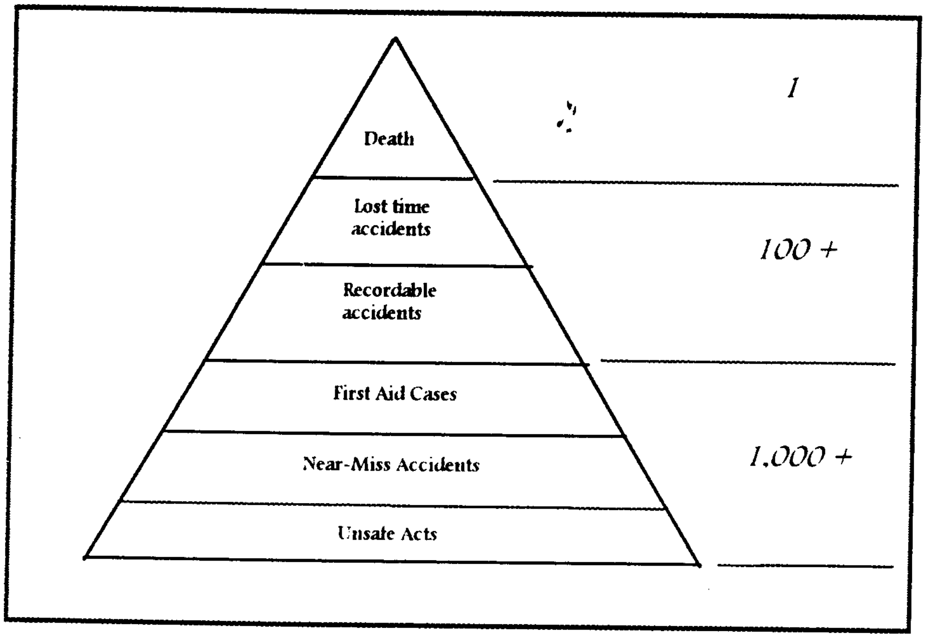

Figure 6: Accident Pyramid (modified from McSween, 1995)

Accident investigations typically focus on the tip of the accident pyramid and attempt to erect barriers to similar accidents, such as personal protection equipment or back-up alarms on construction vehicles. These barriers are intended to prevent the reoccurrence of the same or similar accidents. Accidents continue to occur, however, because the vast majority of the accident pyramid, like an iceberg, remains hidden and not addressed. Human behavior and modern systems are too complicated to predict all the possible interactions which comprise the pyramid's base (Perrow, 1984). Figure 7 illustrates how unique combinations of contributing factors and events can interact with human error to defeat safety programs and result in accidents. The key to accident prevention is to reduce or mitigate the occurrence of human error by focusing on the contributing and compounding human factors that comprise the bulk of the accident pyramid.

Contributing factors	Human Error	Compounding factors	Safety Measures	
Organization;	Slips, lapses,	Organization;	OSHA;	
Equipment;	fumbles,	Equipment;	Safety	ACCI-
Procedures;	mistakes,	Procedures;	programs;	DENT!
Environment.	violations.	Environment	Barriers	

Figure 7: Evolution of accident showing synergistic effects of organizational influences, site conditions, human error and safety measures.

Crisis Management

Accidents often seem to occur unexpectedly. This is probably because people failed to recognize the clues, signs and symptoms of the developing crisis which cumulated in an accident. A crisis can be defined as a rapidly developing sequence of events in which the risks associated with the system rapidly increase to a hazardous state (Bea & Roberts, in press) The complex mix of system factors shown earlier in figure 1 can interact in unique and unpredictable ways to create dangerous situations. Figure 8 shows how danger will build over time until either corrective action is taken or an accident results. The rapidity of the danger build-up will vary by each system.

It is important to realize that even though the individual operator is most often responsible for committing errors that cause accidents, it is the same individual operator who can recognize a danger build-up and safely correct the situation. More often than not, individual operators successfully recognize potentially dangerous situations and successfully correct the situation before it escalates into an accident. The operator's ability to recognize potentially dangerous situations can be improved by warning devices into systems. Additionally, note in figure 8 that training can

dramatically improve the operator's ability to recognize building danger and safely correct the system.

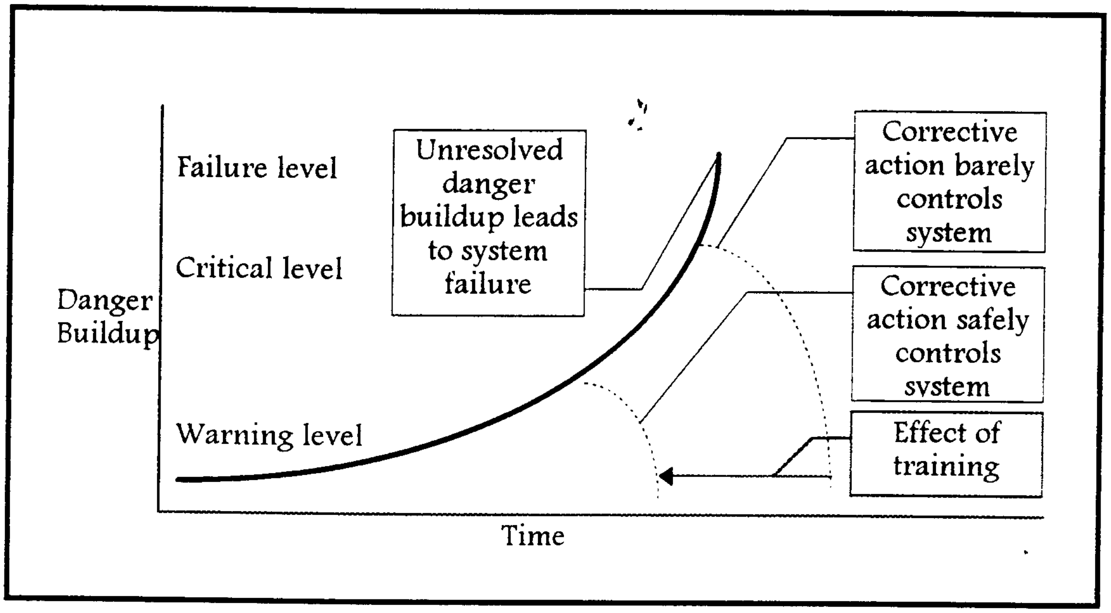

Figure 8: Crisis evolution, resolution, and the effect of training (modified from Bea & Roberts, in press)

3. HUMAN FACTORS IN DIVING

Diving is a means to accomplish work in a normally inaccessible and potentially hazardous environment. Divers perform a wide range of activities underwater, including inspections, maintenance, repair and construction. While working underwater, divers are subjected to high levels of physical and psychological stress due to increased ambient pressures, cold, currents and the limitations of life support equipment. Human factors are significant in diving because the underwater work environment is harsh and alien, and because diver life support systems depend upon technology that is designed, operated and maintained by humans. It must be emphasized that man works in the sea by virtue of technology, not biology. Divers depend upon equipment to perform specific tasks and to provide life support during every dive. Continued improvements in this diving equipment allow man to work deeper and longer. Remotely operated vehicles (ROV's), which are unmanned, allow performance of various tasks in almost all depths for extended periods. Many essential underwater tasks, however, can only be performed or are best performed by a man underwater. A diver is the most versatile underwater tool. He is also the most unpredictable. As man ventures into the sea to perform work underwater, equipment supports his life, but his own behavior may threaten his safety.

Working versus Recreational Diving

This study focuses on professional working divers; nevertheless, the information presented should benefit all divers.[4] It is beneficial to draw a distinction between the professional and recreational diver. The recreational, or sport diver, dives as a hobby and is usually motivated by a desire to explore and witness. The working diver is a professional who dives to perform a specific task or service. Both divers are usually trained and certified, but recreational diving equipment is typically limited to SCUBA, Self Contained Underwater Breathing Apparatus. Working divers are trained to use a variety of diving systems, from SCUBA to deep diving, surface supplied, mixed gas systems. A recreational diver may use some ancillary equipment to enhance enjoyment, such as a light, camera or scooter. The working diver, on the other hand, will almost always use a tool to perform a specific task, such as a video camera for

[4] Some of the referenced papers supporting this study focused on the recreational diver because of the lack of data available from the professional diving community (See Morgan, 1995).

inspections, electrodes for welding or explosives for demolition. Finally, since the goal of recreational diving is personal enjoyment, a decision to abort a dive, perhaps due to ill health or deteriorating weather, normally only affects the diver and his buddy. A working diver faced with the same decision, however, must disappoint a client who needs and expects the diver's services. Thus, it can be argued, the working diver often faces greater pressure to tip the scales balancing service and safety toward service. This study's evaluation of human factors associated with diving will hopefully help the diver and diving supervisor knowledgeably weigh the competing influences and make the best decision when balancing tradeoffs between service and safety.

Factors in Diving

A dive team performing work underwater can be considered a system that is influenced by the six factors shown earlier in figure 1: equipment, procedures, organization, environment, individuals, and interactions. There are unique diving related considerations associated with each of these factors.

Equipment:

Dive equipment can be grouped into four general categories:

- Specialized diver tools (e.g., underwater welding equipment);
- Equipment that helps man adapt to the underwater environment (e.g., fins help a diver move through the water, and a mask helps him see);
- Safety and protective equipment (e.g., a knife to cut free of entanglements; suits to provide both thermal and abrasion protection);
- Life support equipment (e.g., the tank and regulator system that provides breathing gas to the diver).

According to Elliott (1984), "If man is to work safely at the deeper depths, it is further development of equipment in support of the diver that will be particularly important." Diving equipment manufacturers are continuously improving equipment to allow man to dive deeper, longer and safer. All equipment, nonetheless, still has limitations and exerts significant stress on a diver. Tools are often bulky and physically difficult to move and operate underwater. Protective suits can restrict mobility. Fins work muscles differently than walking or running. Regulators require increased breathing effort.

The diver must be able to function within the given limitations of today's equipment. Proper equipment engineering can decrease the physical demands placed upon the diver. It is also crucial that equipment design consider psychological demands. Research by Morgan (1983b) postulated that "anxiety states may be a response to disordered breathing" caused by use of respirators or SCUBA. Morgan, Lanphier, Raglin and O'Connor (1989) went on to show that "some individuals who perform physical exercise while wearing SCUBA sometimes experience respiratory distress and/or panic behavior." Morgan (1983a) argued that while most research and development of SCUBA focuses on the respirator component of the person-respirator interface, more attention needs to be paid to the psychological components.

Procedures

Dive procedures are promulgated in many forms, including the Navy Dive Manual, PADI Dive Manual, OSHA Sub-Part T, Codes of Federal Regulations, specific rules and regulations for individual diving companies, and so on. Separate dive procedures are developed for each type of diving, such as air and mixed gas diving, inshore and offshore diving, or recreational and professional diving. Dive tables that prescribe depth and time limitations are also a subset of procedures which reflect the unique nature of the diver's hyperbaric work environment.

Environment

The underwater work environment exposes divers to physical, psychological and pathological stresses. No other industrial working environment alters normal worker physiology more than diving (Vorosmarti, 1987). Environmental effects include pressure, cold, currents, and limited visibility. Moreover, underwater conditions can change rapidly without warning. The author has experienced dives offshore where unexpected currents arose during the dive, sweeping divers from the intended dive site. Divers must anticipate environmental conditions and effects, and plan accordingly. It is important to recognize that the diving environment cannot be controlled, but the diver can control when and how he enters into the environment.

Individual

The dominant factor controlling diver safety is the individual diver's physical and mental fitness to dive. Considerable research has focused on the physiology of diving,

but little research has been done on the psychology of diving. Detailed lists of physical contraindications to diving have been published[5], and it is well established that diving is a physically demanding job. Some diving tasks require considerable strength and stamina, as well as a reserve of physical and psychological strength sufficient to cope with unexpected situations (Mebane & McIver, unknown). According to Shelanski (1996), however, mental fitness may be at least as important as physical fitness for divers. Indeed, behavioral problems may be more important than physical problems because 'no amount of physical screening can protect a diver from his own stupidity' (Vorosmarti, 1987). Furthermore, since 'the majority of diving accidents are caused by poor judgment or inattention to the basic rules of diving safety...' maturity and responsibility should be evaluated more carefully than physical conditions. (Vorosmarti,1987) Therefore, a diver, whether professional or recreational, should have some minimum capabilities in order to dive safely. It is important to recognize that not everyone has the physical and mental capacity to dive safely. Physical and psychological screening of potential new divers could improve dive safety. Physical screening standards which reflect anticipated work demands are commonly used by commercial and military divers. These standards can vary widely, but the need for physical screening is widely accepted. Psychological screening, conversely, is resisted in spite of the fact that research has successfully developed a unique psychological profile for divers. According to Morgan (1995), divers are "characterized by low scores for measures of anxiety, and high scores for measures of aggression, assertiveness, confidence and sensation-seeking; they also tend to possess an internal locus of control." Moreover, Morgan has successfully used the Spielberger's State-Trait Anxiety Inventory to predict with 88% accuracy which divers amongst a class of new recreational divers would experience panic. Selection of individuals for diving and other high consequence operations should match the individual's mental and physical abilities to job demands (Flin & Slaven, 1995).

Organization

If the dominant controllable factor affecting diver safety is the individual diver, then the organizational factor is the dominant controllable factor affecting the individual

[5] For example, see Vorosmarti, James Jr., MD, (Ed.) (1987), Fitness to Dive. Thirty-fourth Undersea and Hyperbaric Medical Society Workshop. Undersea and Hyperbaric Medical Society, Inc., Bethesda, MD.

diver's behavior. The organization can be viewed at many different levels starting with a two man buddy team and growing to include the dive team, overall organization and entire diving industry. It is important to recognize that all organizational levels exert influences on the individual diver's behavior and performance.

Interactions

This is the most unpredictable factor. Unanticipated interactions between factors can be critical when a diver is working in an isolated hyperbaric environment. Thorough planning and preparation are necessary to minimize unanticipated interactions, and effective coping skills under stress are necessary to control interactions when they do arise.

Panic

The principle cause of diver injury or death is panic, or a loss of control (Morgan, 1995; Elliott & Bennett, 1989; Bachrach, 1987)[6]. An analysis of the human factors associated with diving will define the primary influences which lead to panic, and suggest methods to promote safety.

Dive safety is primarily controlled by the individual diver and his ability to cope with stress underwater (Bachrach, 1987). Figure 9 illustrates the evolution of a dive accident beginning with a diver in a normal psychological and physiological state. Applying a stressor alters the diver's psychological and physiological state, and if the stress becomes excessive the diver's skills will diminish. As previously discussed, stressors may come from human factors, organizational factors, the environment, equipment, procedures or interfaces between any of the above factors (recall figure 1). It should be noted that these stress effects are cumulative. For example, cold water is an environment stressor that will reduce the diver's physical dexterity. Organizational pressure to extend bottom times and improve productivity can increase the cumulative stress level perceived by the diver, while use of a hot-water suit can reduce the stress level.

[6] These studies focused on recreational diving statistics, but the author believes that the statement holds true for professional divers also. More data on human factors in professional diving is needed.

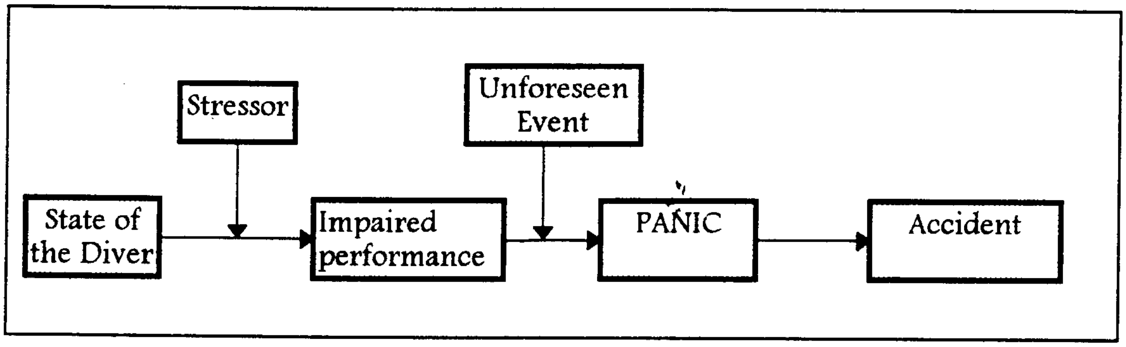

Figure 9: Evolution of an dive accident (Modified from Bachrach)

Normally a diver is able to cope with applied stressors and perform the dive safely. As long as the diver has sufficient capacity for coping, then the stress is relieved or controlled and the operation can continue. If the stress demand exceeds the diver's capacity, then the stressor is beyond the diver's control and an accident may result (Bachrach, 1987).

Coping

Stress response, or coping, as shown earlier in figure 2, is a cognitive process which evaluates a stress situation and available options, then selects the best course of action to respond. It is important that a diver maintains the ability to process information and make decisions while under stress, especially when presented with unforeseen events, as shown in figure 6. The diver's maxim, "stop, breathe, think, act", is a proven method for working through unexpected events.

Stop, Breathe, Think, then Act. This is the maxim for managing unexpected events underwater, and it is taught universally to commercial and recreational divers. The intent is to calm the diver and maintain an ability to cognitively appraise a stress situation.

1. *Stop* any action which may have created or is exacerbating the stress situation.
2. The diver should focus on *breathing*. Experience shows that the majority of dive fatalities are due to drowning even though ample air is still available to the diver. This step should calm the diver's rising anxiety by showing him that adequate life support is on hand.

3. The diver must *think* about the problem and evaluate the options for resolving the imposed stress. The diver is probably now operating in Reason's knowledge-based performance level where training and education can pay dividends.
4. Last, select a preferred option and *act*. This completes the stress response process.

It is important to realize that the dive maxim, "stop, breath, think, act" is generally a good response, however, it is not a panacea for diving emergencies. The response assumes that both time and adequate air supply are available. Experience shows that this is usually true, but not always. Certain situations require immediate instinctive responses which must be ingrained via education, training and retraining. For example, a diver should instinctively exhale whenever ascending to prevent lung overpressurization injuries. If a diver is subject to a collision or upwelling underwater, his natural reaction may be to tense up and hold his breath. This natural reaction could prove fatal if the diver is lifted sufficiently to cause lung overexpansion. Only through training, education and perhaps proper selection will the diver instinctively exhale. Other factors to prevent panic are listed in table 3.

Physical fitness: having a reserve capacity
Training which emphasizes in-water skills and comfort
Medical exams to ensure no hidden contraindications to diving
Fatigue prevention
Age limits

Table 3: Factors to prevent diver panic. (From Bachrach)

4. ORGANIZATIONAL FACTORS IN DIVING

While dive safety is foremost a function of the individual diver's performance, it is the diver's organization which exerts the dominant and controllable influences affecting the diver's performance. The organization often controls the multiple influences acting upon the diver, and organizational factors (such as culture, regulations, structure and supplies) are responsible for the majority of contributing and compounding events leading to accidents. It is important that the individual diver is part of a team which can help him cope with unforeseen circumstances. Methods are needed to help organizations exert positive, rather than detrimental, influence on the diver. Current organizational research into the characteristics of High Reliability Organizations, and the airline industry's Crew Resource Management can help improve organizational factors on two different levels. The former takes a macro-view of the organization, while the later focuses on team development within an organization.

High Reliability Organizations

Background

Many modern organizations operate in hazardous and uncertain environments which have the potential not only to harm employees, but also cause catastrophic harm to the public and surrounding ecosystems. Examples of such organizations include a nuclear power plant or oil refinery. Modern technology has magnified man's ability to do work, but it has also magnified the potentially negative consequences of that work (Wenk, 1986). In organizations where the consequences of an accident can be catastrophic, accidents are intolerable. Consequently, errors that could potentially lead to an accident are unacceptable. Fortunately, many potentially hazardous organizations operate nearly error and accident free, and these organizations have been labeled as High Reliability Organizations (HRO's) (Roberts, 1990).

Organizational researchers have defined high reliability organizations as "technologically complex, potentially hazardous organizations in which accidents can

be catastrophic to the organization and/or society as a whole, but operate nearly accident free" (Roberts, 1994). A good example is the U.S. air traffic control system, where controllers handled over seventy million aircraft flights during the 1980's without a single mid-air collision (Roberts, 1990). Other HRO's which have been studied in depth include Pacific Gas & Electric (PG&E), and the US Navy's aviation program. The product of this research is a list of organizational characteristics that promote reliability, and challenges to some common theories of organizational design.

High reliability characteristics are useful for dive operations even though dive teams do not strictly meet the definition of a 'high reliability organization'. While diving is certainly technologically complex and potentially hazardous, errors would rarely be considered catastrophic to the public or environment. Errors committed underwater, however, can lead to fatal consequences for the individual diver. Therefore, this study strives to improve dive safety by applying the results of research into high reliability organizations.

High Risk Systems

High reliability organizations must overcome two characteristics common to high risk systems: complex interactions and tight coupling (Perrow, 1984; Roberts, 1990a, 1990b). According to Perrow, interactions between system components or procedures can be either linear or complex. "Linear interactions are those in expected and familiar production or maintenance sequence, and those that are quite visible even if unplanned. Complex interactions are those of unfamiliar sequences, or unplanned and unexpected sequences, and either not visible or not immediately comprehensible" (Perrow, 1984). While linear interactions dominate in a system, it is the complex interactions which often have the potential for catastrophic consequences. High reliability organizations, therefore, must somehow compensate for these complex interactions.

Social scientists use the term 'coupling' to describe the strength of relationships within an organization. Loosely coupled systems have loose connections. Tightly coupled systems, on the other hand, are characterized by time dependent processes, invariant process sequences, invariant production goals, and little slack. Time-dependent processes cannot wait for attention. Invariant processes must be completed in an

expected sequence, e.g. B must follow A; and invariant production goals allow only one general production method. Little slack does not allow for any variance from expectations (Perrow, 1984). In general, tight coupling implies a lack of flexibility within the system and its operating procedures. HRO strategies work to control processes, but retain enough flexibility to adapt to unforeseen events.

Characteristics of High Reliability Organizations

Organizational researchers have developed a list of characteristics common to high reliability organizations. These characteristics help the organization overcome complex interactions and tight coupling common to high risk systems and allows the organization to reduce risk and promote reliability. These characteristics, which are listed in table 4, are also appropriate for organizations emphasizing safety.

Focus on Reliability
Adaptive organizational structure
Accurate decision making
Training
Flexibility within formal rules
User-friendly human-system interfaces
Process auditing
Redundancy
Senior management
Culture of reliability

Table 4: Some characteristics of high reliability organizations (from Roberts & Libuser, 1993)

- FOCUS ON RELIABILITY: The dominant characteristic of every HRO is a long-term focus on reliability (Roberts, 1990a). Reliability pervades every aspect of the organization, including personnel, equipment and procedures.
- ADAPTIVE ORGANIZATIONAL STRUCTURE: The majority of HRO's studied are hierarchical structures, but rapidly shift to a decentralized structure when faced with a potential crisis. The formal hierarchy helps keep the organization stay on track during normal operations, while the decentralization adaptation helps improve and expedite decision making in stress situations.

- ACCURATE DECISION MAKING: Operational reliability is a direct result of accurate decisions, both under normal and stressful conditions (Roberts, Stout, Halpern, 1994). If an organization needs to make accurate decisions, then the decision must be allowed to migrate within the organization to the most qualified decision maker for the given situation. Moreover, these decisions must often be expeditious since the complex interactions and tight coupling of high tech systems can cause errors to rapidly escalate into accidents (Roberts, Stout, & Halpern, 1994). When rapid decisions are required in high reliability organizations, the decision is most likely to be made at the point of problem sensing, normally at the operator's level (Roberts, 1994). Normal daily operating decisions are also made at the operator's level; while strategic decisions are pushed up to higher managerial or executive levels. Decisions may also migrate laterally to the most experienced individual in the organization, if he is the most qualified to decide. Good decisions depend upon open, efficient, and effective communications, so information must freely migrate throughout the organization.
- TRAINING: HRO's are constantly conducting training (Roberts. 1994). Training helps improve decision making skills and is an effective means of coping with system complexity. An organization can use training to improve daily performance and to prepare for crisis response. Training must focus on areas where errors may occur and promote the development of recognition and coping skills in the operators, who must recognize and correct errors before they develop into accidents. The earlier an error is identified and corrective action initiated, the easier it is to control. Training improves an individual's ability to perform under stress (recall figure 3) and his ability to recognize and control rapidly developing crisis.
- FLEXIBILITY WITHIN FORMAL RULES: Research shows that formal rules help mitigate risk, if they are followed and enforced (Roberts, 1993). Rules keep the organization on track during normal operations. When faced with a unique and unanticipated crisis, however, formal rules often do not apply and can lead to disaster if followed too rigidly. Under such circumstances the organization must be flexible and reactive (Roberts, 1994).
- USER-FRIENDLY HUMAN-SYSTEM INTERFACES: Human Factors Engineering and ergonomics are important. Engineers tend to believe that the world is uninhabited, and design equipment accordingly (Wenk, 1996). This is a grave error, however,

since the majority of accidents occur during system operations and are caused by people. Equipment and procedures should recognize human limitations, and the extent of automation should reflect the needs of the operator.

- PROCESS AUDITING: HRO's use internal and external auditing of their processes to identify sources of problems and ensure rules are followed. Audits provide a system of checks which keeps the process on target, and promote early detection of errors. Independent checking is especially valuable because it brings untainted views. Thus, the adverse effects of errors are detected and corrected before they escalate into an accident.
- REDUNDANCY: Redundancy in people, equipment, and procedures strengthens the organization so that it can survive minor errors. The organization cannot afford to act like a chain, which is only as strong as the weakest link. Within an organization, redundancy can be achieved in two ways: through duplication and overlap. Duplication provides two or more units performing the same tasks, such as back-up pumps. Overlap implies that neighbors can cover for neighbors, or each man knows the job of the man directly above and below. If a person is lost, someone can step in without a significant loss to the organization. Additionally, redundant monitoring increases the likelihood that an error is detected early and corrective action is taken quickly before it escalates into a larger problem (Roberts, 1994).
- SENIOR MANAGEMENT: Senior management in HRO's look at the big picture, and plan strategically. They act as information and resource distributors, helping various parts of the organization obtain the information and resources they require.
- CULTURE OF RELIABILITY: Culture can be defined as the shared norms and values of a group, or simply as "the way we do things here" (Helmreich, 1996). Once in place, it is difficult to change the organization's culture, but change may occur through a continuous and gradual process. Organizational culture pervades all other high reliability characteristics, and it is the lynch pin which holds the organization together. The organizational culture establishes behavioral norms by rewarding desired behavior and punishing inappropriate behavior. Rewards and punishment are the links between authority, responsibility and accountability within the organization. If an individual is given a responsibility, then he must also be given commensurate authority within the organization to fulfill his

responsibility. Finally, the individual is held accountable through rewards or punishment. In HRO's, reliability is rewarded.

Combating High Risk

The combined effects of HRO characteristics help the organization combat high risk by diffusing complexity and tight coupling. Complex interactions are managed through user-friendly interfaces, training, redundancy and accurate decision making. User-friendly human-system interfaces minimize system complexity. Training helps prepare operators to cope with unexpected events, and improves their decision making. Redundancy ensures there is more than one means to respond to unexpected events, and accurate decision making ensures the response is appropriate. Tight coupling is managed by allowing flexibility within the organization's structure and formal rules. Front-line personnel are given the authority to react as necessary, and the organizational culture holds them accountable for their actions. Reliability is promoted by rewarding reliable behavior. Senior management and continuous process auditing monitor the system and ensure it maintains its focus on reliability.

Crew Resource Management

Crew Resource Management (CRM) is a training methodology which promotes team reliability through development of interpersonal skills. Originally developed for the airline industry, CRM is ideal for any environment where people must interact with technology and each other. It has recently been successfully exported to military aviation, hospital operating rooms, nuclear power plants and corporate management. This study proposes that CRM principles be applied to working dive teams.

The necessity of CRM is illustrated by two points. First, the successful operation of complex, high tech systems usually requires a cohesive team. Second, both the human and machine elements of that system have performance limits. Optimal performance is achieved when both people and equipment operate within their limits. Performance degrades when people or equipment operate outside of these limits (Merritt & Helmreich, in press). Engineers have long recognized equipment limitations. Organizations, however, are only beginning to recognize the limits of the human elements. This recognition of human factors is crucial according to Helmreich because "research into accidents and adverse incidents has shown that the majority involve

human error. Perhaps more significantly, the errors by humans tend to fall in the areas of team coordination and communication, leadership, and decision making." Thus, exceeding performance limits causes breakdowns within the team, which leads to system accidents.

The goal of CRM is to reduce the frequency and mitigate the consequences of human errors (Helmreich & Merritt, 1996). Figure 10 portrays the CRM goal as a multilayered pyramid. The entire pyramid represents all the errors which a team may commit. CRM strives to prevent the majority of these errors, represented by the bottom layer of the pyramid. Since human error can never be completely eliminated, CRM also strives to contain the effects of errors which do occur, and these errors are represented as the pyramid's middle layer. Containment prevents the rapid escalation of an error into an accident. Finally, if accidents do occur, CRM principles help to mitigate the consequences. This is represented by the tip of the pyramid. It is important to recall figure 4 which showed that the one accident represented by the tip of the pyramid is typically preceded by one-million unsafe acts at the base of the accident pyramid. If we can learn from these unsafe acts and near accidents, then fewer accidents should occur.

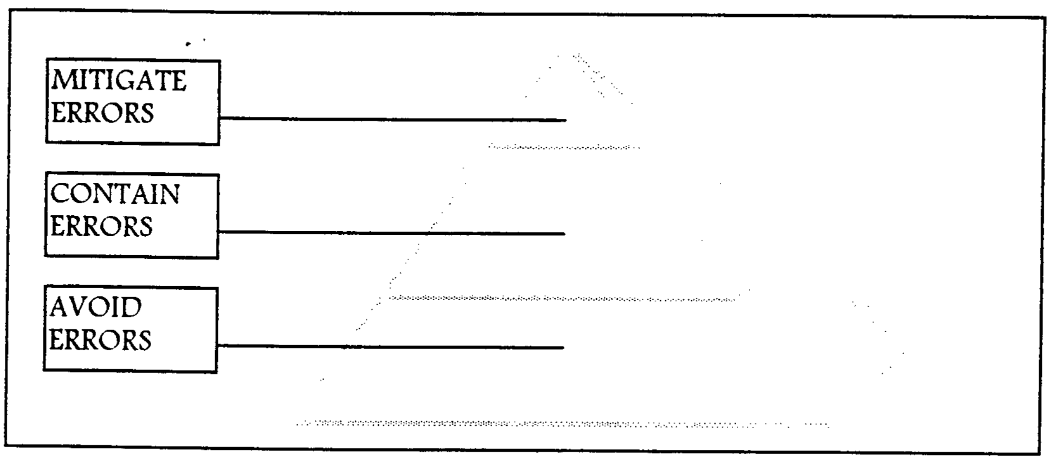

Figure 10: The error troika of CRM (from Helmreich & Merritt, 1996)

CRM strives to reduce human error by understanding the relationship between human performance and stress. It is imperative that the organization recognize the inevitability of human error, and the relationship between error and stress. Stress

should be recognized as a component of all human effort, and not as an individual weakness. An individual's willingness to acknowledge the effects of stress on his or her performance is subject to influence from the national, organizational and professional cultures. Organizations which must operate accident free must encourage its members to admit infallibility and acknowledge the effects of stress. The organization should adopt non-punitive policies regarding everyday error. This does not suggest that organizations accept the consequences or become tolerant of violations (Helmreich and Merritt, 1996).

Training was discussed earlier as a means to improve individual performance under any given stress level. This develops individual competency. CRM demands that individuals first be competent in their individual skill requirements, before they begin team training. Team training is also necessary to develop coordination through interpersonal skills. CRM focuses on team training aspects, and the development of effective interpersonal skills which promote safe team operation. The positive results experienced in commercial aviation and within NASA clearly validate "the operational usefulness of human factors training as a means of improving crew and organizational effectiveness" (Helmreich, 1996b). The elements of CRM are correlated with requisite knowledge, skills and behaviors in Table 5.

ELEMENTS	KNOWLEDGE	SKILLS	BEHAVIORS
Captain's authority	emergencies management use of authority responsibilities leadership decision making	command supervision direction management coordination leadership	timely decisions balance appropriate operational provide direction solicit information
Crew climate	synergy stress management behavior styles team building diversity	respect confidence briefings communications encouragement	admit mistakes interactions inform before act request input listening
Crew development	learning process thinking association competence instruction	encourage explanation feedback discussion demonstration professional	describe feedback professional reinforcement use of simulation
Communication	listening verbal communication non-verbal communication barriers to communication impact of systems	communications questions non-defensive listen verify	sharing objectives defined decisions defined ask questions clear statements
Problem definition	information obstacles biases strategies conditions	recognition assess information recognize wrong recognize bias formulate conclusions	state when wrong discuss significance considerations scan & monitor question
Decision making	tools & methods individual & group inquiry & critique advocacy responsibility anticipating conflict resolution	use resources resolve differences communicate use inquiry resolve conflict advocate solutions	request information question information discuss information state decisions state analyses focus on what is right
Workload management	indicators regulation of information flow task prioritization task assignment planning & preparation	sequence demands clarity planning recognition of indicators take initiative	communications assignments acknowledge briefings expressions plan for expected plan for unexpected
Situation awareness	operational conditions environmental conditions distractions preoccupation irregularities emergencies stress fatigue	monitoring projecting assessment recognition	observing monitoring communications avoid distractions select information ask questions continually assess * where you are * where you have been * where you are going
Resource use	internal resources external resources factors affecting * time * risk * safety * availability	use of crew use of passengers use of information systems use of manuals use of data	ask crew ask passengers ask external sources search manuals search data

Table 5: Crew Resource Management (from Bea & Roberts, in press)

5. IMPLEMENTATION

Improving Dive Safety

Efforts to improve dive safety can take many forms, such as incremental improvements in dive equipment, continued training, or improved depth-time algorithms This paper has argued that the most significant improvement in dive safety can be gained by focusing on human factors and eliminating sources of human error within diving. This assertion is affirmed through expert opinion and dive accident data. If this premise is accepted, then a set of practical tools is necessary to implement human factors awareness in daily dive operations. Such human factor tools must decrease the probability of human error and the effects of errors that do occur. This can be accomplished by managing the contributing and compounding conditions associated with system factors: environment, equipment, procedures, organization, individuals and interactions.

- *Environment.* The underwater environment exerts significant physical and psychological stress that is beyond the diver's control. Divers, therefore, must identify the unique environmental conditions (depth, temperature, etc.) and potential hazards (dangerous marine life, strong currents, etc.) and plan the dive accordingly. The plan must include contingency responses for low probability, but high consequence accidents. Thus a thorough dive plan can mitigate environment stressors. The dive plan must also address equipment and procedural factors, as well as individual and organizational factors.
- *Equipment.* Dive equipment, especially life support equipment, also exerts significant stress on the diver. Research and development must continue to improve equipment ergonomics and physiological support. Also, new equipment designs should emphasize robustness and simplicity in design and operation. In the field, equipment considerations are focused on selection, maintenance and usage. Selecting the right tool for the job at hand is crucial for diver's working remotely in an alien environment. Maintenance is also crucial, especially with life support equipment, to ensure the equipment functions as planned when needed. Finally, the diver must be trained to use the equipment properly. These critical equipment decisions reflect procedural, individual and organizational factors.

- *Procedures.* Diving rules and regulation allow an inherently hazardous operation to be performed safely. Rules, however, are only valuable if they are understood and abided by. The organizational culture often determines whether rules are followed or violated.
- *Organization.* Divers almost always function as members of teams, and the team's organizational culture exerts significant influences on individual behavior and performance. Dive planning was discussed earlier as a means to identify potential hazards and mitigate risks, but the dive plan is only effective if it is implemented successfully. The old adage holds true: plan your dive and dive your plan. The culture of the team will determine the thoroughness of the plan and the effectiveness of its implementation. The desired characteristics of High Reliability Organizations and the techniques of Crew Resource Management can help ensure that the organizational culture emphasizes safety.
- *Individual.* In field operations, all the previous factors are manifested in the actions of the individual operator. Therefore, the individual is the primary focus of human factors efforts to improve dive safety.
- *Interactions.* Interactions are often unforeseen, and are best combated by developing simple, yet robust systems and procedures with loose correlations and redundancy. Also, individual divers must maintain a reserve of physical and emotional strength that will allow them to cope with unexpected interactions.

Human considerations should be incorporated into all of the above factors. Two factors, however, demand special emphasis because they are the most controllable factors, yet are often the factors that are most out of control. Human factors in diving should focus on two controllable areas: first, improving individual awareness of human factors and ability to cope with stress, and second, improving team coordination, reliability and culture.

Improving individual performance under stress

Individual performance under stress situations can be improved by incorporating human factors into initial selection, qualification and follow-up training. Initial diver training should include human factors awareness. Divers must learn their limitations. There is more to this than teaching depth and time limitations. This includes teaching new divers that each individual has unique limitations. Divers must be aware of their own physical and psychological abilities to cope with applied stressors, and recognize

when their performance begins to degrade due to excessive stress. Initial training must also teach new divers how to cope with stress in the working environment. This is typically initiated in the controlled underwater environment of a pool, and then transitions to actual open water conditions. The controlled environment allows instructors to simulate high stress conditions without excessive risk. This high stress training is a common component of military dive training and most commercial training, but not recreational training. The high stress training is important because it teaches the individual diver how to cope with stress. When the in-water training transitions to open-water conditions, the instructor typically does not impose high stress on the new diver. Instead, the environmental conditions add new stress to the diver, teaching him new coping skills.

Coping skills, like any other skill, must be maintained through continuous training and experience. Typically, real-world experience helps the diver develop response templates to stress situations and additional high stress training is not required. Whenever a new dive environment or piece of dive equipment is introduced, however, work-up training should be done to acclimate the diver and allow for the development of response templates.

Implementing Human Factors into Dive Teams

Dive teams should strive to reflect the characteristics of High Reliability Organizations described in chapter 4, and possess a pervasive focus on safety. Crew Resource Management techniques can help develop these desired organizational characteristics in a team. The aviation and space research center at the University of Texas suggests a four phase approach to CRM implementation (Helmreich, in press, 1996b) that can be adapted to successfully implement human factors into dive teams.

1. Diagnose the organization and define areas of concern regarding human factors.
2. Develop a performance based human factors training program tailored to reflect the organization's specific needs, culture and personnel attitudes.
3. Evaluate and validate the effects of the training through participant feedback and empirical follow-up analysis of the team's performance.
4. Continue training and reinforcement of desired behaviors.

Diagnose the organization

Diagnosing an organization is analogous to a medical diagnosis developed during an annual physical examination (Hee, Leverich & Mathur, 1996). The medical examination is conducted in four stages. The first stage is identifying the person to be examined. The second stage is evaluating the patient's health using information obtained through an extensive medical history questionnaire, a listing of the patient's complaints, and a preliminary examination conducted by nurses to obtain the patient's temperature, blood pressure, and other vital signs. During the third stage, the doctor evaluates all the information and identifies specific areas of concern. This third stage is conducted before the doctor ever examines the patient. The fourth stage occurs when the doctor physically evaluates the patient in the examination room.

During the examination, the doctor focuses on areas of concern identified earlier. The doctor asks the patient questions about items written in the medical history questionnaire, and about complaints, examining those areas more closely. The doctor then makes an initial diagnosis, but also orders additional tests to confirm his diagnosis. The doctor may prescribe medication, if necessary, while awaiting the test results to confirm his initial diagnosis.

In this medical example, the interaction between the doctor and the patient is crucial for proper correct diagnosis and treatment. The doctor has the medical knowledge to make a diagnosis based on the information provided; however, only the patient knows his body and he must articulate what ails him. Incomplete or incorrect information can lead to a misdiagnosis. Therefore, it is crucial that accurate information is obtained from the patient (the true expert regarding his body) on how his own body feels. It is important to note that the doctor works with a range of subjective values instead of an exact number when evaluating a patient. The doctor looks for trends in these values to determine if a condition is improving or deteriorating.

The medical examination analogy can be translated into a methodology for diagnosing an organization, with three notable exceptions (Helmreich, 1996b):

- The organizational diagnosis should be team based rather than individual. This emphasizes that safety and operational effectiveness are team responsibilities.

- The diagnosis should include observations of real operations since statistically the majority of accidents occur during operations, and team member behavior is often inconsistent between training and real operations.
- The diagnosis should focus on behaviors implicated in accidents rather than on technical proficiency. The intent of the diagnosis is to identify the presence of behavior that is known to be a contributing or compounding factor in accidents. It is this behavior which leads to degraded performance and technical errors. Thus, the diagnosis focuses on the root causes of accidents. It should be noted that similar behavior-based safety programs have been used successfully in such high risk companies as DuPont to achieve impressive breakthroughs in safety (McSween, 1995).

Diagnosing a dive team starts by identifying the organization and selecting expert evaluators. Just as a doctor is a recognized expert in physiology, the evaluators used to diagnose a dive team must be expert divers. Next, detailed information about the team is gathered. Administrative records listed in table 6 should be reviewed, and the material condition of critical equipment should be inspected. Records from any significant events, either positive or negative, should be reviewed. Information should also be gathered by interviewing team members regarding safety during team operations. From this information, areas of concern regarding the team's operations can be identified. The final step in the initial diagnosis is to observe field operations, focusing on previously identified areas of concern and behaviors implicated in accidents.

Manuals	Training	Certifications
Instructions	Maintenance	Medical records
Publications	Personnel	Prior inspection results
Operating logs		

Table 6: Administrative records and materials for review (from Commander, 1995)

CRM has enjoyed notable success improving aviation safety by focusing on observable behavior during operations. CRM's expert observers record targeted behaviors that are known to precede errors and accidents on a checklist (called the Line/LOS Version 4). Checklist data and comments are later used to critique crew performance. Differences

between desired performance and observed performance can define learning objectives for performance based training. In order to capitalize on the CRM's success, the CRM checklist has been adapted for dive teams. The resultant diving human factors checklist focuses on observable behavior which data and experience have shown precedes dive accidents. The checklist should prove useful in the initial diagnosis of a dive team's human factors awareness and abilities, and in accident investigations to help identify the compounding and contributing behaviors which lead to the accident. The checklist and instructions for its use are provided as appendix A.

Training program development

Human factors training starts with awareness and acceptance of stress as it impacts performance. Specific behavioral techniques which can help reduce the likelihood of an error are taught to counter the influence of stress and reduce error (Helmreich, 1996). These techniques are listed in Table 7. Once individuals understand the relationship between stress and performance, CRM transitions to team training in a simulated operational environment and focuses on development of effective interpersonal skills. Team training should be tailored to the specific organization and focus on areas of concern identified during the initial diagnosis of the team.

Cross-checking	Verification of communication
Preparation	Speaking up to express concerns
Planning	Sharing a mental model of the situation
Vigilance	

Table 7: Individual behavioral techniques to reduce error (from Helmreich, 1996)

Evaluate training

Immediately following the training, the relevance and impact of the training should be measured through participant feedback. These feedback should be used as lessons learned to improve the training. Follow-up analysis of team performance should be done to identify trends in the teams performance.

Reinforcing human factors skills

Human factors skills are primarily interpersonal skills which allow individuals to work effectively as team members. Just like any physical skill, interpersonal skills must be practiced and continually reinforced to remain most effective. VonDerLinn (1995) has

identified the top three barriers to successful training that the organization should address in order to reinforce training objectives:

1. Lack of reinforcement on the job;
2. Interference from the immediate work environment;
3. Non-supportive organizational culture.

VonDerLinn also recommends the following measures to overcome training barriers:

1. The organization must reward safety and reliability over production, schedule, or cost.
2. Company policy must be rewritten to reflect new attitudes.
3. All levels of the organization must support training goals.

Accident Investigations

The Human Factors in Diving Checklist (Appendix A) was developed primarily to record behaviors during real time observations of dive operations. The checklist, however, can also be useful during post accident investigations to record targeted behaviors. The checklist was so employed to evaluate a U.S. Navy dive accident that resulted in a diver fatality attributed in part to human error. The checklist was used to review a first-hand account of the accident and identify targeted behaviors. The results show where human factors acted as contributing and compounding events that lead to errors and eventually a fatal accident. The following sections summarize the first-hand account of the 1974 fatality. Contributing and compounding events are identified, and then correlated to the Human Factors in Diving Checklist. The resultant scores from the checklist are provided and evaluated. Finally, conclusions regarding the checklists usefulness as a post-accident investigation tool are offered.

Background

On 11 June 1974, a U.S. Navy Seabee diver attached to Underwater Construction Team One died in a diving accident. The direct cause of death is officially Arterial Gas Embolism, however; numerous contributing events preceded this direct cause. Additionally, after the diver surfaced and before the time of death, several compounding factors exacerbated the situation. A statement from the diver's buddy was reviewed to identify potential contributing and compounding factors which are listed below. This is by no means an exhaustive list of potential factors, nor is it

intended to place any blame on individuals or commands involved. The list is compiled in an effort to identify those human factors which actually did occur in a real-life tragedy, and to use this information to critique the effectiveness of the Dive Team Human Factors Checklist. The statement from the diver's buddy is included in this appendix.

SCENARIO

A Navy dive team was attempting to stabilize an underwater cable by installing spit pipe around the cable in approximately 100 feet of water. Weather was fair. Visibility good. Two divers were in the water using SCUBA.

CONTRIBUTING FACTORS

All factors listed in approximately chronological order and are negative unless otherwise noted:

Pre-dive

1. Diver was a smoker.
2. Diver got a good nights sleep the previous evening. (Positive factor)
3. Dive team felt pressured to complete work because support vessel was only available for a short time.
4. The diver was relatively new to the team and was frequently teased. This behavior was probably normal for the group and applied to old as well as new members. However, teasing a new member may exert additional pressures on that member to prove his worth.
5. Two relatively inexperienced divers paired as buddy team.
6. Poor coordination of dive team put divers in the water before material (split pipe)was ready. As a result, the diver used air while waiting on the surface while the buddy did not use air.
7. Initial dive brief was not clearly communicated or understood by both divers. More experienced buddy was given authority to change dive profile during dive, but did diver realize this?
8. Effects of nitrogen narcosis unplanned for even though depth was expected to exceed 90 feet and diver had complained of previous narcosis at same depth.

9. The diver violated a well established SCUBA diving rule that requires all divers to end the dive and return to the surface before their tank pressure reaches 500 PSI.
10. The diver had a tendency to deplete his air supply faster than most of the other divers. The dive plan, however, assumed that both divers could work up to the maximum time limits for the given depth. The plan did not account for the individual's limitations.
11. Initial dive training did not emphasize rescue skills and the importance of exhalation during buddy breathing.
12. Diver was slightly seasick prior to the dive.

<u>Dive</u>

1. Diver was using a borrowed regulator which was adjusted to breath especially easy. This is significant because the diver was already known as a heavy breather.
2. Heavy tool bag dragged divers down and caused the buddy team to separate.
3. Diver had difficulty equalizing on descent. This delayed the descent time.
4. Buddies did not coordinate and communicate regarding change to dive profile.
5. Underwater work was physically difficult.
6. Diver may have experienced some nitrogen narcosis.
7. The diver failed to routinely monitor his air supply, and depleted his air without warning.
8. Both diver and buddy failed to abort dive when pressure gage indicated the bottle was empty.
9. Buddy used inconsistent hand signals which may have created confusion.
10. Buddy failed to intervene and force abortion of dive when gage read zero.
11. Buddy failed to monitor situation and recognize diver's unsafe behavior.
12. Dive team culture condoned breathing tank dry if necessary to complete a task. In short, the team rewarded production over safety.
13. Buddy's failure to act early allowed the situation to develop into a crisis, and as a result the buddy had to ascend without his fins. This would limit his ability to help the diver during the ascent.

14. Diver never had formal training on Fenzy, a critical piece of dive equipment which could have saved his life.
15. Diver showed evidence of panic during ascent when he grabbed buddy's regulator.
16. Entanglement with mooring line during ascent probably caused diver to panic and make an uncontrolled rapid ascent from approximately 10 feet.

DIRECT CAUSE OF DEATH:

Arterial Gas Embolism probably the result of an uncontrolled rapid ascent accompanied by breath holding.

COMPOUNDING FACTORS (Post dive):

1. Chamber was readily available. (Positive factor)
2. Transport to the chamber was fast and efficient (Positive factor)

SCORE SUMMARY FROM DIVE TEAM HUMAN FACTORS CHECKLIST:

	Pre-Dive	Dive	Post-Dive
• Team communications & coordination	2.0	N/A	N/A
• Situational awareness & decision making	1.8	2.0	2.0
• Auditing	N/A	1.0	N/A
• Resources	2.7	2.7	2.5
• Operational procedures	3.0	3.0	3.0
• Training	N/A	2.0	N/A
• Individual fitness to dive	2.1	2.0	2.0
• Special situations	2.0	2.0	3.0
• Overall observation	N/A	N/A	N/A

Table 8: Accident investigation score summary

EVALUATION

The Dive Team Human Factors Checklist is intended to be used for observations of real-time operations and facilitate the recording of targeted behaviors. Its effectiveness as a post-accident analytical tool is limited by the fact that team behavior cannot be

observed, but instead must be conjectured from limited accounts of witnesses. Scores from a post-accident review will be negatively skewed as a result of the investigation's focus on what went wrong, and because of the limited information available. Obviously this lack of information is an obstacle that all accident investigations must overcome, so the checklist may offer some valuable insight. In the post-accident context, the checklist can help correlate actual events to human factors that contributed to or compounded the situation. The scores from a post-accident review are not as important as this correlation to key behaviors. This correlation can help identify areas of concern regarding human factors within the team, and the scores may help focus attention on the most critical areas of concern. Thus the checklist can help sift through a variety of post-accident information, and should be useful in the development of post-accident lessons learned.

The scores listed above indicate that the dive team only meet the minimal expectations in the majority of the evaluated areas. Two areas were below the minimum expectations: (1) situational awareness and decision making during the pre-dive phase, and (2) auditing during the dive. Thus the checklist helped narrow the earlier lists of contributing and compounding factors down to the most critical areas. Moreover, in the author's opinion, the resultant focus on situational awareness, decision making and auditing truly does identify the most critical areas of concern. This information can now be used to develop "lessons learned" which focus of the most important elements of the accident. It is important to recognize, however, that all of the contributing and compounding factors played a role in the final outcome and therefore all factors should be addressed if resources permit.

CONCLUSIONS

The Dive Team Human Factors Checklist proved to be a useful tool for post-accident investigations. It provided a structure for correlating a historical account of an accident to specific behaviors that are likely to have contributed toward or compounded the severity of the accident. This type of review provides valuable "lessons learned" that can help prevent future accidents. Further refinement of the checklist to increase its relevance to diving and the accuracy of its targeted behaviors should improve its usefulness.

6. RECOMMENDATIONS

1. Dive accident data should be collected for the professional dive community as well as the recreational diving community. This data should track the presence of specific observable behaviors that are known to contribute to dive incidents and accidents.
2. Accidents attributed to 'human error' should be further categorized according to observed behaviors which directly caused the accident (e.g., mistake, slip, violation, ignorance, communications, planning, selection, limitation, preparation, training, or impairment).
3. Initial training for all divers should include formal classroom discussion of human factors. High stress situations should be simulated in a controlled environment to promote the development of coping skills underwater.
4. Dive teams should be regularly assessed for human factors effectiveness. The draft Human Factors in Diving Checklist (appendix A) could be used as a tool to guide human factor evaluations of dive teams.
5. Periodic training in human factors should be offered to reinforce human factors skills.

Recommendation for further research

The HF Checklist should be used to observe operational dives, and edited as necessary to improve focus on observable behavior that might contribute to dive accidents.

Appendix A

DIVE TEAM HUMAN FACTORS CHECKLIST

DIVE TEAM HUMAN FACTORS CHECKLIST*

Purpose: The purpose of this checklist is to (1) get an initial "temperature" of the dive team with respect to human factors, and (2) identify initial areas of concern which may warrant further examination.

Event data:

Date (mo./yr.): ....

Observer: ....

Command observed: ....

Equipment: ....

* Dive rig: ....

* Air/gas supply: ....

Dive scenario: ....

* Task: ....

* Depth: ....

Temperature: ....

* air: ....

* water: ....

Surface conditions: ....

* swell: ....

* current: ....

* weather: ....

Bottom conditions: ....

* current: ....

* bottom type: ....

* temperature: ....

* visibility: ....

Dive team members: ....

* Dive supervisor: ....

* Diver #1: ....

* Diver #2: ....

* Standby diver: ....

* Tenders for #1: ....

* Tenders for #2: ....

* Communications: ....

* Charts: ....

* MDV: ....

* Diving Officer: ....

---

*This checklist was created by adapting Helmreich's Line/LOS Version 4 aviation checklist for diving. (See Helmreich, Robert L., Butler Roy E., Taggart, William R., & Wilhelm, John A. (1995) "The NASA/University of Texas/FAA Line/LOS Checklist: A behavioral marker-based checklist for CRM skills assessment." Aerospace Crew Research Project, Technical Paper 94-02.) The checklist also models portions of the FLAIM II methodology for assessing human factors. (See Hee, Derrick. (1996). Basic Minimal Questions for FLAIM II. Unpublished. Marine Technology and Management Group, University of California, Berkeley.

Evaluation criteria:

Note: If performance is rated either poor (1) or outstanding (4), the observer should briefly explain the observed behavior in the "comments" section.

Grade	*Summary*	*Description*
1	POOR	Observed performance is significantly below expectation. This includes instances where necessary behavior was not present, and examples of inappropriate behavior that was detrimental to mission effectiveness.
2	Minimum Expectations	Observed performance meets minimum requirements but there is ample room for improvement. This level of performance is less than desired for effective team operations.
3	Standard	The demonstrated behavior promotes and maintains team effectiveness. This is the level of performance that should be normally occurring in dive operations.
4	Outstanding	Performance represents exceptional skill in the application of specific behaviors, and serves as a model for teamwork - truly noteworthy and effective.

Evaluation:

The following evaluation criteria focus on specific behaviors that serve as indicators of effective human factors management in diving. It is an attempt to gather targeted data in areas known to be direct, contributing or compounding causes of human error and accidents in diving. They are not intended to be an exhaustive list of behavior which should be seen, but rather as examples of effective behavior which provide a standard for comparison.

Observers must be recognized diving experts with a superior level of knowledge, experience and training. This is crucial because only an expert will be able to recognize subtle but important differences in operations and behaviors.

Observers are asked to focus on team effectiveness more than individual performance, except where evaluation criteria specifically target a specified team member. Occasionally, individuals may stand out from the others during team activities and the observer should record this exceptional behavior in the "comments". Not all behaviors will be seen during each dive phase, therefore it is acceptable to leave those sections of the checklist blank.

1. Team concept and environment for open communications established and/or maintained, e.g., crew members listen with patience, do not interrupt or "talk over", do not rush through the briefings, make eye contact as appropriate.
2. Briefings are operationally thorough, interesting, and address team coordination and planning for potential problems. Expectations are set for how possible deviations from normal operations are to be handled, e.g. tainted air source.
3. Representatives from serviced ship or coordinating commands are included as part of team in briefings, as appropriate, and guidelines are established for coordination between commands.
4. Group climate is appropriate to operational situation, e.g., presence of social conversation at appropriate times. Team ensures that non-operational factors, such as social interaction, do not interfere with necessary tasks.
5. Team members ask questions regarding team actions and decisions, e.g., proposed method for task accomplishment.
6. Team members speak up and state their information with appropriate persistence, until there is some clear resolution and decision, e.g., "I'm uncomfortable with...Let's ..."
7. Each team member is assigned a clearly defined role. Each member understand and is qualified to perform assigned responsibilities.
8. All team members participate fully in the dive operation; e.g., everyone pulls their own weight.
9. Dive Supervisor effectively balances command authority and team member participation. The supervisor considers team

suggestions, but acts decisively when the situation requires.				
10. Operational decisions are clearly stated to and acknowledged by all team members, including coordinating commands when appropriate, e.g., "everyone is on the same page."				

Situation Awareness and Decision Making	Pre-dive	Dive	Post-dive	Specific Comments
1. Team members demonstrate high levels of vigilance (monitoring, scanning, cross-checking, auditing) in both high and low workload conditions, e.g., everyone is aware of work status and progress.				
2. Team prepares for unexpected or contingency situations including weather, tides, etc.; e.g., they "stay ahead of the curve".				
3. Team actions avoid creation of self-imposed workload, deadlines and stress, e.g., proper planning and situational awareness avoids diving in marginal or unsafe conditions.				
4. Dive is scheduled and effectively controlled to prevent excessive delays or time crunches; e.g., team members are not just standing around or forced to rush.				
5. Diver displays a high level of vigilance regarding his equipment, environment and task loading. (Note: this is especially critical for SCUBA operations)				
6. Decisions are allowed to migrate within the team to the person most qualified to make the decision; e.g., is the diver's judgment trusted by topside?				

Auditing	Pre-dive	Dive	Post-dive	Specific Comments
1. Positive and negative performance feedback is given at appropriate times and is made a positive learning experience for the whole crew; feedback is specific, objective, based on observable behavior, and given constructively.				
2. Performance feedback is accepted objectively and non-defensively.				
3. Team members are aware of teammate performance levels, and intercede if performance is degraded or unsafe.				
4. Performance feedback from external auditors is accepted objectively and non-defensively.				

Resources	Pre-dive	Dive	Post-dive	Specific Comments
1. Operational tasks are prioritized to allow sufficient resources for dealing effectively with primary operational tasks before secondary tasks.				
2. Do individual team members believe that they have the right tools for the job at hand?				
3. Does the diver feel confident that the equipment is well maintained and in good working order?				
4. Support from external commands is meets dive team expectations; e.g., does the ship provide a hot lunch?				

Operational procedures	Pre-dive	Dive	Post-dive	Specific Comments
1. Communications between diver and topside are in accordance with standard Navy procedures; e.g., commands are verified through repeat-backs.				
2. Dive manual procedures are followed, and manual is consulted as necessary.				

Training	Pre-dive	Dive	Post-dive	Specific Comments
1. When appropriate, crew members take the initiative and time to share operational knowledge and experience, especially with new team members, revised operations or new equipment.				
2. Dive team members are rotated through dive team assignments.				
3. Team members are encouraged and given the opportunity to pursue additional qualifications; e.g., chamber operator or dive supervisor.				
4. Team members received adequate formal and/or on-the-job training in assigned equipment and responsibilities.		2		Diver was not trained in use of Fenzy.
5. Team members are cross-trained and qualified in multiple roles, e.g., console operator, tender, diver, etc.				

Individual Fitness to dive	Pre-dive	Dive	Post-dive	Specific Comments
1. Team members recognize and report work overloads in self and others, e.g., stating "I'm getting overloaded down here", or "Can I get help or can you take over...?".				
2. Team culture recognizes human limitations and rewards admissions of fallibility or lack of fitness to dive, e.g., "I have some congestion and should not dive today" or "I'm distracted because of...and should not dive today".				
3. Diver is qualified, experienced and confident in use of dive *rig and tools.*				
4. Diver is qualified, experienced and confident in dive *environment*, e.g., dive may be in kelp, at night or in zero visibility.				
5. Diver's experience and training are current, e.g., when was last time the diver was in the water using this rig?				
6. Diver's ability, experience and training match specific job requirements.				

7. Diver feels physically and mentally fit to dive; e.g. diver is not overly tired, nervous or boastful.
8. Diver is not predisposed to DCS; e.g., smoker, overweight, over 40, dehydrated, fatigued, etc.
9. Diver is able to evaluate options and cope with unexpected events.
10. Dive plan accounts for individual diver strengths and weaknesses; e.g., diver may be a heavy breather and requires a shorter schedule.
11. Buddy assignments reflect qualifications, experience and task requirements; e.g., inexperienced diver is paired with experience diver.
12. Dive buddies communicate and cooperate effectively; e.g., the diver's get along and make an effective team.
13. Team members recognize fatigue and take specific steps to help maintain team alertness, e.g., social conversation, physical activity, caffeine management.
14. Team members recognize effects of exposure, either hypothermia or heat exhaustion, and take specific steps to help maintain individual health and alertness, e.g., warm or cold drinks as appropriate, crew rotations, etc.

[illegible]	Pre-dive	Dive	Post-dive	Specific Comments

1. When conflicts arise, the team remains focused on the problem or situation at hand. Conflict issues are identified and resolved without losing focus on mission.
2. Team members listen actively to ideas and opinions and admit mistakes when wrong
3. Safety is consistently emphasized over production and deadlines.
4. New team members are orientated and accepted as part of the team and not expected to "prove themselves".
5. Incidents and accidents are recorded and reported as appropriate, and without fear of reprisal.
6. Team is sheltered from unreasonable external expectations.

[illegible]	[illegible]	[illegible]	[illegible]	Specific Comments
1. Overall technical proficiency				
2. Overall team effectiveness				

Notes:

APPENDIX B

Accident Investigation

B. EVALUATION OF DIVING FATALITY

DIVE TEAM HUMAN FACTORS CHECKLIST*

Purpose: The purpose of this checklist is to (1) get an initial "temperature" of the dive team with respect to human factors, and (2) identify initial areas of concern which may warrant further examination.

Event data:

Date (mo./yr.): 11 June 1974

Reviewer: M.A. Blumenberg

Command reviewed: UCT 1

Equipment:..

* Dive rig: SCUBA

* Air/gas supply: Air

Dive scenario:....................................

* Task: Cable stabilization

* Depth: 110 fsw

Temperature:......................................

* air: unknown

* water: unknown

Surface conditions:...............................

* swell: unknown

* current: slight

* weather: fair

Bottom conditions:..

* current: none

* bottom type: sand

* temperature: comfortable

* visibility: 50-60 ft.

Dive team members:......................................

* Dive supervisor: anonymous

* Diver #1: Ernest Bellavita (fatality)

* Diver #2: William McDevitt (buddy)

* Standby diver: anonymous

* Tenders for #1: anonymous

* Tenders for #2: anonymous

* Communications: anonymous

* Charts: anonymous

* MDV: anonymous

* Diving Officer: anonymous

Team Communication & Coordination	Pre-Dive	Dive	Post-Dive	Specific Comments
1. Team concept and environment for open communications established and/or maintained, e.g., crew members listen with patience, do not interrupt or "talk over", do not rush through the briefings, make eye contact as appropriate.				Unknown
2. Briefings are operationally thorough, interesting, and address team coordination and planning for potential problems. Expectations are set for how possible deviations from normal operations are to be handled, e.g. tainted air source.	1			Did not plan for nitrogen narcosis
3. Representatives from serviced ship or coordinating commands are included as part of team in briefings, as appropriate, and guidelines are established for coordination between commands.				N/A
4. Group climate is appropriate to operational situation, e.g., presence of social conversation at appropriate times. Team ensures that non-operational factors, such as social interaction, do not interfere with necessary tasks.				Unknown
5. Team members ask questions regarding team actions and decisions, e.g., proposed method for task accomplishment.	2			
6. Team members speak up and state their information with appropriate persistence, until there is some clear resolution and decision, e.g., "I'm uncomfortable with...Let's ..."				Unknown
7. Each team member is assigned a clearly defined role. Each member understand and is qualified to perform assigned responsibilities.	3			
8. All team members participate fully in the dive operation; e.g., everyone pulls their own weight.	3			
9. Dive Supervisor effectively balances command authority and team member participation. The supervisor considers team suggestions, but acts decisively (con't)				Unknown

when the situation requires.				
10. Operational decisions are clearly stated to and acknowledged by all team members, including coordinating commands when appropriate, e.g., "everyone is on the same page."	1			1. Divers did not receive the same pre-dive instructions from the Diving Supervisor. 2. Divers forced to hold on surface while waiting for split pipe which was not ready.

Notes:

Situation Awareness and Decision Making	Pre-dive	Dive	Post dive	Specific Comments
1. Team members demonstrate high levels of vigilance (monitoring, scanning, cross-checking, auditing) in both high and low workload conditions, e.g., everyone is aware of work status and progress.	1	2		Pre: Corpsman was aware of diver's seasickness, but dive supervisor apparently was not. Dive: Buddy was aware of diver's problems.
2. Team prepares for unexpected or contingency situations including weather, tides, etc.; e.g., they "stay ahead of the curve".	2		1	Pre: Planned for possible variations in depth; Post: Insufficient support for chamber operations.
3. Team actions avoid creation of self-imposed workload, deadlines and stress, e.g., proper planning and situational awareness avoids diving in marginal or unsafe conditions.	2	2		Pending loss of dive platform added pressure to get the work accomplished.
4. Dive is scheduled and effectively controlled to prevent excessive delays or time crunches; e.g., team members are not just standing around or forced to rush.	2	2	3	Diver's forced to wait on surface until split-pipe was ready. Diver's should not have entered the water until all materials were ready.
5. Diver displays a high level of vigilance regarding his equipment, environment and task loading. (Note: this is especially critical for SCUBA operations)	2	2		Diver's personal regulator was not functioning.
6. Decisions are allowed to migrate within the team to the person most qualified to make the decision; e.g., is the diver's judgment trusted by topside?				Unknown

Notes:

[illegible]	Pre-dive	Dive	Post-dive	Specific Comments
1. Positive and negative performance feedback is given at appropriate times and is made a positive learning experience for the whole crew; feedback is specific, objective, based on observable behavior, and given constructively.				Unknown
2. Performance feedback is accepted objectively and non-defensively.				Unknown
3. Team members are aware of teammate performance levels, and intercede if performance is degraded or unsafe.		1		Buddy recognized potential problems, but failed to act.
4. Performance feedback from external auditors is accepted objectively and non-defensively.				N/A

Notes:

Resources	Pre-dive	Dive	Post-dive	Specific Comments
1. Operational tasks are prioritized to allow sufficient resources for dealing effectively with primary operational tasks before secondary tasks.	3	3	3	
2. Do individual team members believe that they have the right tools for the job at hand?	3	3	2	Insufficient resources for chamber operation.
3. Does the diver feel confident that the equipment is well maintained and in good working order?	2	2		(1) Diver borrowed regulator since his was not is good order. (2) Fenzy's reportedly in "rough shape"
4. Support from external commands is meets dive team expectations; e.g., does the ship provide a hot lunch?				N/A

Notes:

Operational procedures	Pre-dive	Dive	Post-dive	Specific Comments
1. Communications between diver and topside are in accordance with standard Navy procedures; e.g., commands are verified through repeat-backs.				N/A for SCUBA operations without tending lines.
2. Dive manual procedures are followed, and manual is consulted as necessary.	3	3	3	

Notes:

Training	Pre-dive	Dive	Post dive	Specific Comments
1. When appropriate, crew members take the initiative and time to share operational knowledge and experience, especially with new team members, revised operations or new equipment.				Unknown
2. Dive team members are rotated through dive team assignments.				Unknown
3. Team members are encouraged and given the opportunity to pursue additional qualifications; e.g., chamber operator or dive supervisor.				Unknown
4. Team members received adequate formal and/or on-the-job training in assigned equipment and responsibilities.		2		Diver was not trained in use of Fenzy.
5. Team members are cross-trained and qualified in multiple roles, e.g., console operator, tender, diver, etc.				Unknown

Notes:

[illegible] to dive	Pre-dive	Dive	Post-dive	Specific Comments
1. Team members recognize and report work overloads in self and others, e.g., stating "I'm getting overloaded down here", or "Can I get help or can you take over...?".		3		Diver handed off heavy tool bag to buddy.
2. Team culture recognizes human limitations and rewards admissions of fallibility or lack of fitness to dive, e.g., "I have some congestion and should not dive today" or "I'm distracted because of...and should not dive today".	1	1		Team culture criticized diver for being a heavy breather instead of recognizing that everyone has a unique air demand.
3. Diver is qualified, experienced and confident in use of dive *rig and tools.*		1		Diver was not formally trained on Fenzy.
4. Diver is qualified, experienced and confident in dive *environment*, e.g., dive may be in kelp, at night or in zero visibility.		2		Diver has limited experience diving over 100 fsw, and his confidence may have been low.
5. Diver's experience and training are current, e.g., when was last time the diver was in the water using this rig?	3	3		
6. Diver's ability, experience and training match specific job requirements.	3	3		
7. Diver feels physically and mentally fit to dive; e.g. diver is not overly tired, nervous or boastful.	2			Diver felt slightly seasick before dive.
8. Diver is not predisposed to DCS; e.g., smoker, overweight, over 40, dehydrated, fatigued, etc.	2	2	2	Diver was a smoker.
9. Diver is able to evaluate options and cope with unexpected events.		1		Diver did not respond appropriately to early signs of pending accident.
10. Dive plan accounts for individual diver strengths and weaknesses; e.g., diver may be a heavy breather and requires a shorter schedule.	1	1		(1) Dive supervisor did not account for diver's record of heavy breathing. (2) Dive team failed to abort dive plan when air supply ran low.
11. Buddy assignments reflect qualifications, experience and task requirements; e.g., inexperienced diver is paired with experience diver.	1			Both divers has limited experience.
12. Dive buddies communicate and cooperate effectively; e.g., the diver's get along and make an effective team.	3	3		

13. Team members recognize fatigue and take specific steps to help maintain team alertness, e.g., social (con't) conversation, physical activity, caffeine management.	3			Diver slept well the previous night.
14. Team members recognize effects of exposure, either hypothermia or heat exhaustion, and take specific steps to help maintain individual health and alertness, e.g., warm or cold drinks as appropriate, crew rotations, etc.				N/A

Notes:

[illegible]	Pre-dive	Dive	Post-dive	Specific Comments
1. When conflicts arise, the team remains focused on the problem or situation at hand. Conflict issues are identified and resolved without losing focus on mission.			3	The team reacted efficiently to the dive accident.
2. Team members listen actively to ideas and opinions and admit mistakes when wrong				Unknown
3. Safety is consistently emphasized over production and deadlines.	2	2		Diver was more concerned about getting the job done than his depleted air supply.
4. New team members are orientated and accepted as part of the team and not expected to "prove themselves".	2			Diver felt a need to prove himself, and this forced him to work longer than was safe.
5. Incidents and accidents are recorded and reported as appropriate, and without fear of reprisal.				Unknown
6. Team is sheltered from unreasonable external expectations.	2			Pending loss of dive platform added pressure on team to get the work done.

Notes:

[illegible]	Pre-dive	Dive	Post-dive	Specific Comments
1. Overall technical proficiency				Unknown
2. Overall team effectiveness				Unknown

Notes:

Personal statement of William Michael MCDEVITT, BU2(DV), U. 62
Navy, 194-42-8217, Underwater Construction Team ONE, provide
the Investigating Officer on 18 June 1974.

I have been requested to make a statement providing my knowledge relative to the diving incident which occurred on 11 June 1974 in which EOCA Ernest Bellavita was injured.

I have also been advised:

(1) That I have the right to remain silent and make no statement at all;

(2) That any statement I do make may be used as evidence against me in a trial by Court-Martial;

(3) That I have the right to consult with a lawyer prior to any questioning;

(4) That I have the right to have such lawyer present during the interview;

(5) That I have the right to terminate this interview at any time for any reason;

I understand my rights as related to me and as set forth above. With that understanding, I have decided that I do not desire to remain silent, that I do not desire to consult with a lawyer at this time, and that I do not desire to have such a lawyer present during this interview. At this time, I desire to make the following voluntary statement. This statement is made with an understanding of my rights as previously related to me and as set forth above, and it is made with no threats having been made or promises extended to me:

I am a second class diver and graduated from second class diving school at Harbor Clearance Unit Two in Little Creek, Virginia in June 1973. In July of 1973 I attended basic Underwater Constructor Technician School in Port Hueneme, California and graduated from there in September; hence after, I was assigned with Underwater Construction Team ONE. Previously I have been civilian certified by NAUI and PADI both; got my certification on Guam before I became Navy certified. I did some sport diving there; other than that I haven't done any sport diving. On Guam, the deepest I ever went was approximately 100 feet; I don't remember ever going any deeper than that. I didn't keep any logs on my dives but I do remember that I went 100 feet. On those dives, I used single 72 open-circuit scuba. When I graduated from second class diving school, LT [redacted] who was the diving officer in NMCB-40, told me that they had too many divers because they didn't anticipate so many graduating. He told me that they had one guy that had to get orders somewhere and I was the only eligible at the time, so I was sent to NMCB-71. Within a week from when I checked in to NMCB-71, they sent me PRE to UCT-1. Other than recall dives, I helped take out the pier at Newport; it was approximately a two-month job. It consisted of underwater sawing with a chain saw, taking out a steel railway and cleaning

up of debris that was left on the bottom; most of the job was sawing and cleaning up the debris. We were at 35 feet, which the deepest. That was March and April, 1974. My diving experience really boils down to some sport diving during that one deployment to Guam, some 30 to 40-foot level pier removal work over in Newport and then about eight dives in the Azores prior to the day of the accident, other than the dives I made while I was in both Underwater Constructor School and Second Class School. I also went through the New London Escape Training. Bellavita had also gone through this training; I hate to say that I am positive about anything, but I remember he was they with us; he was one of the guys that did real well. As I remember, he did real well on his ascent. As for myself, I felt that it was good experience; it was, you know, something that you would use maybe sometime and it was a good experience.

I went straight to the Azores; we left Davisville on the 18th and arrived in Santa Maria on the 23rd of May. We just helped in between; we stopped at Terceiras and helped with the mike boats momentarily until we could go over to Santa Maria. Before the day of the accident, I would say I had made approximately eight dives; I had an estimated two hours total dive time on Santa Maria.

On the day of the accident, we left the pier in the other mike boat (we had one mike boat that was moored out at our job site and we left in the other mike boat) which took us out to the one that was moored. We unloaded all our gear and all our bottles and immediately two divers were sent down (one was Al [redacted] and the other was LT [redacted]); they were sent down to survey the cable that had been already spliced and placed in the water; they were to survey and find out where the split pipe was to go. The split pipe was to prevent abrasion and chafing on the bottom. They were to mark off the spots and come back up and tell us, Bellavita and I were both dressed at this time and were sitting on the wing walls waiting to go in and they were down inside the well of the mike boat. When we took off, I felt the instructions were clear and I knew exactly what we were supposed to do. I did not feel as though they were expecting us to do too much while we were down there because before a dive, they usually make sure that you have enough to do; they don't pressure you to get something done; I feel they give you more than you can do in case you do get done in enough time, you have enough to do won there so you are not a wasted dive.

I knew the LCM-8's were going to be taken away from us. From what I had heard, they were to be back in Lajes the 15th. Knowing this, I felt that it was pretty nip and tuck as far as getting the job done. I can't really remember Ernie expressing an opinion on it, but the opinion was pretty negative around with everybody, as far as getting the job done by the 15th. I don't think anybody, other than ENS [redacted], thought we were going to get it done by then. I just don't personally think that we could have gotten it done. With respect to backup or contingencies if we lost the boats, they had talked with the Portuguese Port Captain; he had offered some of his small boats; I'm not exactly sure of what model or anything they were, but he said we could use them for dropping of split pipe and diving off of if we

needed them. Of course, we had our whaler and Zodiac, but it not really too good for handling the weight or lengths of the pipe. So, we did have that contingency. What LT [redacted] and ENS [redacted] had for other contingencies, I don't know.

Knowing that we were going to lose the boats and having the desire to get the job done and just trying to get that very last bolt in while we were down there could have been a big part of it. Ernie Bellavita was the type of guy that was a really sincere man and he didn't like to get teased that much about diving; he was new and he didn't like to be teased about it. At the time I didn't think that much about it, but after I thought about it for a little bit, I feel maybe the reason he stayed down as long as he did was because he didn't want to come up and maybe get razzed or have them saying, "You guys didn't any pipe on at all; what did you guys do down there," etc. He may have feared, not really feared, but he just didn't want to put up with the razzing.

After LT [redacted] and Al [redacted] gave us the overall picture of what we were to do, we waited around a few more minutes until they dropped split pipe for the anchor and they brought it back over to the mike boat, etc., then we entered the water. When we entered the water, they hadn't gotten the split pipe ready to be put on the line; there was a small current and we were drifting away so we grabbed onto the whaler (one of us on each side of it); they had some fenders which were thrown over it and we held on to the fenders and we were just towed around really slow waiting for them to get this done. I hadn't known it at the time, but when I was being towed around, I didn't use my air (and I just kept my head out of the water) but Ernie did, from what the guys in the whaler saw and the guys on the mike boat. I couldn't see him because he was on the other side, but I understand he had his regulator in his mouth and he was breathing off it then. We just held on to the whaler and they just stayed in the vicinity of the descent line, you know, just slowly moving around just waiting for them to get ready with the split pipe.

To repeat, we were initially on the mike boat where we got dressed; then we jumped in and swam over to the descent line; they weren't ready for us (they hadn't gotten the split pipe tied together and ready); we were at the descent line and the whaler came over and we grabbed a hold of the whaler, so we didn't go back to the mike boat, we just patrolled around in the vicinity. While we were waiting in the water I didn't that notice the Bellavita was using his mouthpiece at that time; I'm not sure who told me, but it was the general opinion of people that knew something about it that Bellavita had his mouthpiece in his mouth and I also think Mills, who was the diving supervisor at the time, said that his thoughts were that Bellavita had his mouthpiece in.

After being towed around for approximately three or four minutes, they took us over to our descent line; I grabbed a hold of the descent line, Bellavita came over by me and the tool bag was lowered. The tool bag was fairly heavy also. It had bolts in it, ratchets, a piece of pipe for us as a ratchet, spud wrenches, and some fire hose which we had cut for use against chafing

inside the split pipe. This was handed over the side of the whaler; Ernie Bellavita and I each took a handle on this and started our descent. Before all this took place, Bellavita said he may have some trouble clearing and if he did, he would just hand me the bag. I don't know why he told me that, whether he had a congested head or you know maybe he needed both hands to clear when he went down and he wasn't going to have the use of both hands; you know, he usually had one hand on the descent line when he went down and cleared with the other and this time he wouldn't have the use of his hands, so he said if he hand any trouble, he would give me the bag. I had made no observation of him having a cold or anything at the time. We started our descent and I suppose about 30 feet, or so below the surface he started having trouble clearing and he seemed to be pretty much troubled and the weight of this bag was taking us down; you know, it was hard to fight against the weight of the bag, so he gave me the bag. I held on to the bag and he was clearing. I couldn't hold on to the bag and stay with him both, because it was pretty heavy, so I went down, I assume 20 feet maybe, until I could see bottom and I dropped the bag so I could see where it was when it landed. By that time he had gotten down to where I was. He still had trouble clearing, but we went down together. After I dropped the bag, we went down together and he had trouble clearing the whole time and it was, I would say, a lengthy time for descent, as far as descents go, because he did have trouble clearing. I could tell he was having trouble because when you descend, you have to clear the pressure in the ears. When you do it, one means is to hold the mask up underneath your noes and blow, and several time he even took his mask off and pinched his nose, then put his mask back on and cleared that way. That's somewhat of a last resort to take your mask off and pinch your nose, because you usually don't take your mask off for anything. When he did that, I assumed he was having much difficulty clearing.

The visibility was good; we had, I assume, about 50 or 60 feet visibility. We got to the bottom after what I would roughly estimate as three of four minutes. Also, a personal opinion of myself is that when you do clear, you use a lot of air; you use a lot of air trying to blow and work your Eustachian tube or whatever trying to get your ears to equalize, because when I have been diving and I have had trouble clearing, I have noticed that I have used a lot of air just trying to clear.

After we arrived at the bottom, we went over to our anchor line, which was the split pipe they had dropped, and picked it up and moved it approximately 50 to 75 feet, at the most, closer to the splice where we were to put the pipe on. After moving it over, we took off our fins and put them in the tool bag and then signaled for them to send down the split pipe.

(I left something out in the report also: Before I left the surface, they told me they had taken a sounding and the sounding said 108 feet, and they told me they were going to put me on a 110-foot table which was a 20-minute stay, and that if when I went down and we had gone any deeper, it would be up to my discretion to change it to a 15-minute stay. When we went over to move the anchor line, we had to go down into a small hole to

pick up the split pipe anchor. It wasn't over a couple of fe deep, both when we had gotten on the bottom, I had checked Bellavita's depth gauge which said 100 and I looked at mine and it had said 108. Therefore, I put us back to a 15-minute stop down there because we had to go down in that hole plus I took the higher reading of the depth gauges. When I decided to go from a 20 to 15-minute schedule, I guess Bellavita still thought we were on a 20-minute schedule because I didn't tell him. Mills, our diving supervisor, instructed us to use a 20-minute schedule, but up to my discretion upon the bottom because there is current and the sounding line wouldn't be 100% accurate.

When we signaled for the split pipe on the anchor line, it immediately came down (it's hard to estimate under water) but I assume about half the way, it got stuck; the two lines bided; the line that was attached to the split pipe and the line which it was sliding on separated a little bit and it was binding. I shook the line while Ernie finished taking off his fins and putting them in the tool bag. I shook the line and the stuck pipe came down 20 feet maybe. I kept shaking it but it wouldn't come down. Ernie went up to the split pipe; he loosened it and sent it down. It came down and I took out my knife and cut the line off of it which was holding it on. We carried the split pipe over to the break, went back over to the tool bag and got a piece of this fire hose and placed it into one of the sections of the split pipe, placed it over the cables and placed the other piece on top of it. It was hard to maneuver, hard to work around because this had the "preform" on it, what they call a lemon; we were putting split pipe right over this lemon which was a bulge in the cable. It was more or less a clamp to hold on the split pipe where the splice was. It was hard to maneuver because usually the cable wasn't this big. We had a little bit of trouble getting it all underneath there and getting it all arranged the way we wanted it.

When we had finished straightening this out and getting it the way we wanted, Ernie reached over, touched me and showed me his seaview gauge which read zero. It may have been a little bit more than zero. When you look at a seaview gauge, you just look at it to see where it is. You know, this wasn't something that you try to remember every time. I just looked over to his seaview and it said around zero, so I reached back and was going to trip his reserve for him. I assumed that there was still air in his bottles and that he was still sucking, because he put his hand up and with the same motion I reached back there, he put his hand up. I gave him a thumbs up. The thumbs up means you wanted to go up, let's go up, and he still had his hand up. In the diving world, thumbs up just means go up, but I thought about it later and down around the team down there, I had a habit of doing this (thumb up indication that something was OK) and I felt later maybe he could have misinterpreted me. I thought maybe at the time, maybe he misinterpreted it, or maybe he didn't even see it because we were working. Also, I feel that he may have had some nitrogen narcosis. I feel that because the first time he dove there, I went down with him also and when he went down we were only 90 feet, which was the deepest we were at, and he said he felt some narcosis then. He said he felt like he didn't have any motivation, he just wanted to look around, he didn't want to do

the work. He said that he just felt a little dull. I didn' dive with him on his second dive, but I had heard that he sa 67 the second time down, he felt it also and I assumed this time he had a little narcosis and his senses may have been dulled somewhat then too. I didn't experience any narcosis; I did the very first time I went down there, but after that I didn't experience any myself. I don't know if it's just a difference in body metabolism or what.

When he had his hand up and signaled me, I just backed off and started straightening the pipe. It wasn't one of these things where he looked right at me and said no, you know, it was just one of these, "I am working, just keep working" deals. I was at one end of the pipe and he was at the other end; we were just straightening it out, getting it ready to put in. It's not really hard to explain how a guy's gauge can read zero and yet say everything is OK, because on several occasions when I've gone down and my gauge has been zero and I wanted to get a few more minutes of diving in, I would put up with the extra hard breathing, sucking of the air, knowing my reserve is there. I would just put up with the extra hard breathing before I would trip my reserve. It's hard to, suck that air out once it gets down, but you can do it. I didn't think much about it at the time because everything seemed to be going all right; you know, other than him having trouble clearing, everything was just a standard dive just like any other one we have done.

After we straightened out the pipe, we went over to the tool bag to get our tools and our bolts out. When we went over there, I remember him reaching back; I don't specifically remember looking at him to see if he tripped his reserve or what, but I assume that's what he did then as he reached back. I was digging and I can remember him reaching back and assume he tripped his reserve. We got our bolts out, got our wrenches out, got our ratchet out, and I went over to the end of the split pipe; he put on his fins then; he swam over to the split pipe with me. He picked up a piece of pipe to hold it together; I put a bolt underneath it and just as I was about to put the nut on, he went to me, he pointed to his seaview gauge. I looked at it his time and I remember positively that he had less than 100 pounds, but it wasn't reading zero, yet he had less than 100 pounds, up I gave him a thumbs up. He started up the ascent line and I didn't even bother to put my fins on because when you get down that low, it's fairly critical.

The instructor's we received regarding our ascent were that upon ascent the whaler had a ten-foot line attached to the side of it with a shackle on it to keep it down. We were to go over to the whaler and hang off there for a couple minutes; just as a precautionary measure; we had been doing this the whole job, just as a precautionary manner to eliminate any excess nitrogen which would be forced in our blood; we had been ding this all along. This was routine and we had every intention of doing it. Now, this was left up to the supervisors and the people in the whaler also. If we had been down there like ten minutes and we were supposed to be down 15 minutes, usually they wouldn't do it. They would pull the shackle up and you would come right up to the boat, but if you came up and saw the whaler and it had the

shackle down, you would hang off it and the guy in the whaler usually had a mask and he should stick his head under the water and signal two minutes, or whatever decompression time the supervisor designated. The supervisor would time the operation, then the guy in the whaler would pull on the line from the whaler and signal you to come up. They would give you four pulls to come up.

We started up the ascent line and he had his own regulator, his own mouthpiece and everything. He was using his own air from his own jugs and everything, and he hadn't signaled that he was having any trouble or anything. We got about half the way up, which I assume took a minute to get about half the way. He looked like his breathing was a little bit labored. This whole time, we had been together, right beside each other. I reached down and turned on my f_enzy. I have a f enzy life vest which has the small bottle which you can breathe off of also in case you have an emergency. I turned a little bit of air on into my frenzy and he reached over and grabbed the hose and pushed the button and started breathing off of it. I can't say for sure that he pushed the button, but I feel sure he did as he knew how to operate a frenzy. As far as knowing whether I saw bubbles coming out to know if he was breathing, you know it wasn't one of those things where I tried to remember if he was breathing or not, because my mouthpiece is right here in front of my face and my bubbles are coming out. I wish I could say for sure, but I can't say for sure if he was breathing or if he was holding his breath. As a rough estimate, I would say he took four or five breaths off of it. He had never had any formal instruction on how to use the frenzy, but he and I both worked in scuba repair at the Team and our job was maintenance on scuba-related equipment. Just before then, we had just gotten these f enzies back; we only had four or five of them. We had gotten them back from Bermuda and they weren't in real good condition; they had salt buildup, etc., so we did some maintenance on them and cleaned them up, scrubbed all of the salt off of them, loosened them up and put some silicone on them to keep them lubricated. He was, if I remember correctly, there with us and he helped us to do this; so, he knew something about them, so he should have known to push the button, I feel that he knew. He took four or five breaths off of my f enzy and put it back down. I can't really remember if he reached back and grabbed his regulator then, but I don't think he did. All this time, we are ascending. I can't remember specifics of what he did, but just a moment after he set the f enzy down, he reached over and grabbed my mouthpiece. He didn't give me a signal that he was out of air and that he wanted to buddy breathe; he just reached over and grabbed my mouthpiece and put it in his mouth, and he did exhale and inhale. He took four or five pretty deep breaths then. I am positive then that he was exhaling and inhaling because I was watching him because he had my air, you know, and I wanted to make sure he just took a few breaths. I was not hurting for air during this time, so as far as needing the air, I just kept on ascending; in fact, I'm not sure even whether I had exhausted air as we were ascending while he was breathing off of my regulator. I don't really remember. I can see where he had his trouble, you know, because I, myself, don't remember concentrating on saying blow those bubbles out you know, exhaust them. You know, that's

a mistake on my part. I assume I did because I'm all right. When we were coming up that line, we were hanging on to it. 69 had one hand on the line, one hand on Ernie, and Ernie had his other hand on me. We were right together, standard buddy-breathing procedure; we were right beside each other.

I will start off from where he had my regulator. I took some breaths off of it. A little bit later after we ascended, I can remember reaching down and exhausting some of the air out of my frenzy, because I was rising and it was getting bigger and was tightening around me and I didn't want to shoot to the surface. I can remember reaching up, pushing the button and exhausting some of the air out of it. When he was using the frenzy, I don't really remember whether he looked like he was being satisfied or dissatisfied by it, or really how he looked. I remember looking at him when he was using it and can remember his taking a breath and he didn't give me any indication that he was sucking in salt water or was having any trouble; it was probably neglect on my part, but I just didn't look at him that much. During the ascend, I was just watching the surface and looking at the bottom to make sure we were getting somewhere.

With respect to lessons learned or for future training in cases like this as to whether it would be better procedure to let your buddy use the regulator and the mouthpiece, and you use the f enzy, I would say that I could have existed using the f.enzy, but I'm not saying it would be better procedure because the hose is going across and who knows what kind of entanglement you could get into. I don't see where there would be one, but it's possible.

Before I am going to give him my air, I have to know that he needs it or that he wants it. The standard signal is the hand at the throat and to feed me air. At no time during the dive did he give that signal to me and that's why I assumed he was all right, but just as a precautionary measure, I guess, is the only reason I put some air in my f enzy. The little bottle that goes into the frenzy does not have a gauge on it. This gets filled before each dive. After the dive, you blow up your vest and get rid of all of the salt water that may be in it and you leave your vest blown up to make sure when you come back the next morning that it is still the same way you left it. Then you know that you don't have any trouble with holes in it or anything. You fill the frenzy bottle by taking it from the vest and putting it on a regular size bottle, opening the valves and letting the air cascade into the bottle. In the way of time, I believe the frenzy would be good for a couple of minutes.

After he took four or five breaths from me and I had exhausted some of the air from this f enzy, he took the regulator out of his mouth and he placed it right back in my mouth because I had one hand on the ascent line and my other hand on him. I reached up and straightened it and everything. I had just taken a couple of breaths when we hit that mooring line. I just felt it brushing up against my shoulder. We were pretty close together and i'm not really sure where it hit him, whether it hit him right on the head or it got caught between his head and his bottles. I thought that's where it did. You know, I couldn't

exactly see because of the bubbles and because he was flaili little, but I remember looking down and he was flailing a little; with the same instant that I looked down and made a movement towards him, he was gone already. He has gotten himself free from the line and was on the way to the surface, so I am sure he couldn't have been tangled in the line more than five seconds. I don't remember specifically whether he was kicking his feet, but as fast as he was going from the mooring line to the surface, I'm sure he was. He had his flippers on, but I didn't. Just before he broke the surface, he ripped of his mask. The line didn't knock his mask off; there is the possibility that the line could have hit his mask and it filled with water or it could have knocked it cockeyed or something. All I remember was looking at him and just before he broke surface, he ripped off his mask. My estimate of the mooring line was that I don't believe it was more than ten feet below the surface. Everybody was thinking that's where he had his troubles, but I personally don't feel that's where he had his troubles.

The normal procedure on the up would be to look over to the whaler for the shackle that is hanging down and head over to it. At the time, I didn't think about it; I probably would have thought about it as we neared the surface, but with the fact that we were buddy breathing then, I didn't think about it. It would have been very easy for us to surface and then just go right back down to ten feet. I don't think this dive was that critical because we hadn't even been there our full 15 minutes.

When he reached the surface, he had his mask off. I reached the surface just a moment behind him and when I came up, he said, "I think I fucked myself up!" I could not see any expression on his face of any pain at all and I said, "Oh, you are going to be all right Ern," or something to that effect.

When he came up, Scott said he came fairly far out of the water and he knew something was wrong, but anyway, the whaler was over there just a moment after we reached the surface. I started swimming towards the whaler; I swam away from Ernie because the procedure was for the whaler to come in between us and grab, and we take off our weight belts and our tanks. The guys in the whaler would help us and assist us, and we would climb over either side of the whaler. I remember Bellavita was moving towards the whaler and I can't remember anything unusual about the way he was swimming. It was just a matter of seconds before the whaler was there. They were right over there by us and just as he was going around the front of the whaler and the whaler was coming between us, I heard him say, "No, I think I really did," and Trostle that was on the whaler with Scott came over to help me on and I told him to go help Bellavita because I think he hurt himself. Trostle went over and helped Bellavita and I was in the water there a while just hanging on, and then I took off my weight belt, put it in the whaler and I looked up over the edge and I saw that they had Ernie laying over the front of the thing and I figured he must really be hurt bad, so I climbed up into the whaler myself and I had one shoulder strap of my tanks on and I climbed up into the whaler, and held onto my tanks and then I pulled them up in. When I got up to the front of the whaler, he was going out of consciousness then; he was groaning a little bit

and just slipped away you know into unconsciousness, and when got there Scott was hitting him in the face a couple of times71 shaking him and he was saying, "Ernie, where does it hurt, tell me Ernie where is the pain"; you know, "What do you feel?" and then he went unconscious. They took the whaler right over to the mike boat, picked up the corpsman, Hastings, picked up Mills who was the diving supervisor (he brought the Diving Manual with him); left off Trostle; we also goth the Ambu bag; we started right in for the pier. The corpsman put the Ambu bag on Bellavita and was trying to revive him, and I looked through the diving manual until I found the treatment tables and I didn't know exactly which table we were going to use; so I gave it to Scott who looked up the table that he planned on using. When we reached the pier (the time it took was 20 minutes or so; someone said 23 or something like that; I don't really remember; it seemed like a long time). LTJG Parisi was already on the dock there waiting so we just beached the whaler; I pulled up the engine and Mills just took the boat right up on the concrete; we pulled Ernie out of the boat; they had the little stretcher that comes out of the chamber already down there waiting for us; there were Portuguese all around that helped us get him out of the boat and up to the chamber; we set him half way into the chamber, cut his wet suit top off of him; pulled his wet suit top off of him and set him right in the chamber and started the treatment. This was my first experience, but the treatment went very well; they did everything according to the book; they did a fine job as far as the treatment goes.

Going back a little, I didn't hear him say it, but Scott said that just before he climbed into the boat (he didn't climb into the boat, they said they dragged him; they pulled him up in the boat), just before when he was at the edge of the whaler, he said, "My hand's numb, I can't feel my hand." Scott also said that some time when they were pulling him in or when they had him in, he said, "My legs are numb, I can't feel my left side, "something to that effect, that he had numbness in his legs, but other than that, that was all that he said. I didn't hear any of this because I was down in the water.

I was with him during the whole procedure up even until he died; I assisted in bringing up the compressor and we had to rig fittings to go from the compressor right to the volume tanks on the chamber and our compressor couldn't keep up with the air that they were using in the chamber, so SW1 Reynolds was there so he and I, and I don't know who all helped, but I remember he was there and he was one of the main men who was helping in getting air for the chamber. We jury-rigged a setup to run some line directly from double 77's to cascade into the volume tanks so that in case we really needed it, we could fill up these volume tanks on the recompression chamber from our scuba bottles; we had only used four of them on the dive, so all of our scuba jugs were filled, probable about ten or 12 of them. They also found another compressor up at the airport. They started making provisions to move the chamber up there.

/ When Bellavita was in the chamber, he was screaming. I don't remember how long after he was in the chamber, that he regained consciousness or semi-consciousness; he was screaming for help

and saying things to the effect, "Oh my God, I'm going to die, help me"; he did a lot of screaming - it was pretty bad. As him being conscious after he got out of the chamber, the corpsman could probable tell you the details; they logged everything in the log books; he could probably tell you the details of when he went in and out of consciousness, but after he had lost consciousness that time, he never regained consciousness again.

Going back again to our ascent, and I was talking about the point where he was flailing and when he hit the line, I lost him momentarily; I looked down for him and at the same moment he was shooting to the surface ripping off his mask just before breaking surface; it's not that I didn't know where he was - I knew where he was; I knew he was at the line, but when he hit the line, I was still ascending; I was still going up. I had some air in my frenzy and it was taking me up. When he hit the line, I felt it brush up against me a little bit and I reached back, and just looked down and I could see him just flailing or trying to get it out and he was just moving really fast and I just made my movement towards him and he was gone. I just passed him; when he hit the line, he just stopped. At the time I wasn't positive what had happened or that there was a line there that he hit; I just felt something brush up against my shoulder. I didn't think, "Well, there's that mooring line." I just brushed it off and he hit it and I knew he wasn't there. I guess you could say I lost him momentarily. I didn't know where he was just for a brief second. Then I stopped -- I had hold of the ascent line; I wasn't shooting the surface; I had hold of the ascent line, and was just making a movement and he was free and just shot to the surface. He then went by me. At that point he had his mask on until just before he reached the surface and I can remember looking at him vividly and he took his mask and ripped it off; and he shook his head and got the water out of his face and everything. I don't know if his mask was full of water or what. When he hit the mooring line, after he left, he was moving pretty fast. The last time he had his mouthpiece in was about half way, I would say about 60 feet. Ernie was little different than anybody else, he used more air than I think anybody on the whole team. He really sucked some air, I don't think he was real badly out of shape; he was a strong man. He wasn't weak or anything like that. When he got in the water, he really worked.

There was never any struggling between Ernie and myself, other than he took my mouthpiece from me and I didn't think anything about it because I had air and if he was having trouble, it was all right, he could have as much air as he wanted. There was never a struggle between us; the only time he seemed to get shook up was when he hit that mooring line, and I personally feel that by that time, he knew that something was the matter. I don't think that it was when he hit the mooring line that did it. I just feel that he knew, you know, he knew something was wrong when he hit the line because he did flail so much. I think that he already had some difficulty before that point. I don't know if he had difficulty, physical difficulty but I feel that he knew that something was physically the matter with me. I don't think he was running out of air and he panicked or anything like that because he knew he had my air right there and he didn't have to worry about that aspect, but well, I don't know, but I think that

maybe he probably held his breath part of the way up or when had his own air, he was holding his breath, hoping the air w 73 expand and then he would get some good breaths, and he held his breath. But, I don't remember seeing him hold his breath; I can't really say what happened; that's just my opinion.

I was a known fact that he used a lot of air; he breathes pretty hard and pretty heavy and deep; maybe the pressure had something to do with it. He didn't use a token amount of air -- it wasn't like a whole set of jugs in a half hour or something like that on the surface, but usually he would be one of the first ones to run out of air. On the other dive that I had with him previously, at more like 90 feet, he did not run out of air then, but somebody said he breathed out a whole set before they completed their tasks on another dive. He almost ran out of air when he was with me; we made an 80 or 90-foot dive; we installed the shackling into the mooring system which we put it down there. I didn't go on reserve then, but I don't think he did either; I can't really remember.

When we came to surface, I don't know what my tanks were registering because I didn't look at my seaview; you know, when there's an emergency like that, you don't think of everything.

With respect to being in a situation where two guys are down at the bottom and one is deciding to stay too long and the other buddy is saying let's go up and, for some unknown reason , the other guy is electing to stay, and what options would the other buddy have to try and get this other guy to come up if he has lost his judgment --- well, one, you can go ahead and let him run out of air and if you have a sufficient amount of air, you could buddy breathe with him the whole way up; or you could start taking off and hope that he would com with you. It's really hard to say. When a man trips his reserve, he is supposed to start his ascent then. I wasn't persistent in saying to go to the surface; probably it was a big mistake on my part in not being persistent to go up, but I felt the man knows his capabilities; he is a diver; he knows what he can do as a diver. We both were inexperienced divers. He graduated from diving school just after I did and neither one of us was that experienced. In school, in Little Creek, they made a point of it for us to know that when you tried your reserve when you were diving, to leave the bottom, and if you should ever run out of air on the bottom and you trip your reserve and there's not air, we would practice free ascents -- just in case the situation ever happened. I don not recall any specific instruction that tells buddies that when you are going up buddy breathing to be looking for air bubbles, to watch tat particular situation. Usually, the instructors would probable hopefully assume that you would do that. Then again, a lot of times in school, you can't even see you buddy because the water is so dirty; you can't see him, you can't see bubbles. Maybe if we were diving in clear water in school.

As a person, Bellavita was a good guy; he was one of those guys that everybody liked; he was always joking -- he was Italian and everybody teased him about being Italian and he would joke right back. I don't feel that there was anybody that didn't really like him. As far as his physical condition, he wasn't in real

good shape, but I don't think he was in bad shape -- he smoke he had an occasional beer now and then, nothing excessive. T night before this dive he was sleeping. I know that because previously we had been on the splice team and I'm not exactly sure, but I think he was out there 34 hours straight the night before. Not the nigh before the accident, but the previous night. We went out during the day and relieved the splice team that was out there; we rigged our cable and everything, and did the splice that night and it carried into the next day. We didn't get off the mike boats until something like 4:00; well he left a little bit earlier -- he might have been out there only about 30 hours. He took the whaler and went back in to get some guys and let them bring the whaler out, and they just told him to just go ahead and stay there, but somewhere in the area of 30 hours, he had been up straight and he went back to the hotel and I didn't see him, but I knew that he went back to sleep because he said, "I had a good night's sleep last night, I went to bed early."

I didn't notice any apparent discomfort from him sitting his suit for so long, but the doc, the corpsmen two are all pretty close said that Ernie had said that he insisted they would let him get in the water because he was feeling a little queasy and when you get in the water, it disappears for some reason. The corpsman told me that Ernie had said I wish they would let me get in the water, I feel a little queasy, a little sick.

The equipment UCT ONE uses is good equipment. I feel it was good before the deployment; we maintain everything up and ready for our deployments, and when we get back from our deployments, everything comes in whether it's bad or not, everything comes back in (as far as SCUBA gear) and we clean it all up and give it overall maintenance, make sure it's silicone, make sure there's no worn parts. They are a little tight on money, they have been tight with money, trying to get money out of whoever they try to get it out of, I assume CBLANT. You know, I am one-sided because I would like to have more stuff than I do have (mostly parts); in fact we didn't take any regulator parts with us this time because we shipped a lot of our stuff to Virginia and we just took spare regulators instead of taking the parts with us. We had 18 bottles and that's a good amount for the amount of diving we did, but Mills, who is in charge of SCUBA repair, had extra regulators with him seaview gauges, etc.

Bellavita was not wearing his own regulator; he was wearing Scott's. His regulator had gone bad; the rubber mouthpiece had a hole in it. We did not have a spare mouthpiece, so he used Scott's that day. I don't know when he discovered it was bad. As far as Scott's regulator, I have a log down there and if I maintained it, I have it logged in my log, but I am pretty sure I didn't do it. In fact, I think Scott worked on his a little bit himself. He is fairly knowledgeable about it; I think he set the OBP on his himself. I remember his saying something about it was really easy to breathe off of his because he had set the OBP that way that it would free flow a little bit at the surface because he had adjusted his OBP that way.

With respect to being a little short of maintenance dollars, I

don't know of a case where we asked for more spare parts or repair parts where we couldn't get them. One time, we put in75 big stack of request chits for repair parts and Senior Chief called me in, and I assume he called Mills in also, and asked me why did we want all of this gear. I just told him with the new man coming in and in view of UCT taking over all of the divers that we were going to need them, and it was better to have them than run out of something and miss something and not have them and have to wait on them. There were no situations over in the Azores with any equipment that we would like to have done something to, but couldn't because of lack of parts of SCUBA gear. In fact, we had several bottles that had gone down and had leaks in them or something but we just try to repair them and we had one bottle that was bad so we tried to use the parts from it. We tried to repair them, but they didn't seem to hold air, so we just put them back in the locker. They are pretty picky when it comes to things like that. If gear isn't up, they don't even fuss with it. We wait until we get back to the States to repair it; in the meantime, we use whatever we have. As I said before, we had spare regulators, etc.; there wasn't really a demand for parts and for the regulators to be fixed over there because we had spares and we weren't hurting for equipment, as far as that goes.

As far as any recommendations or opinions that might be helpful in the future to help prevent any more accidents of this nature. I don't have any because actually right now I don't know from the autopsy what he actually died from. I don't really know, I think he had some nitrogen narcosis and maybe he shouldn't have been diving that day because he wasn't feel good. As far as I know, he was not taking any medication of any kind.

With respect to the time as to when I went down and came up, I had set my watch for a 20-minute dive. I think it was in the area of somewhere around 20 until one when we took off, I can't really remember right now. I set it for 20 minutes but we didn't stay even close to our full 20 minute planned dive. I remember looking and seeing I was five minutes away from actual ascent time. I remember seeing that we had five minutes left when we were trying to get the belts in (five minutes from 15 minutes). When we went into the hole after the piece of pipe, I moved the dial on my watch to a 15 minute dive, but I know we didn't stay our actual 15 minutes, but I don't actually know what the total time of the dive was. I didn't even think about finding out what it was, but I think we started our descent in the area of around 20 until one.

The above statement is true to the best of my knowledge and belief.

Witnessed:

[redacted]

[redacted]

Investigating Officer

REFERENCES

American Bureau of Shipping. (1996). The Human Element: Teamwork. Surveyor. September, 1996. Volume 27, Number 3.

Bachrach, Arthur J., & Egstrom, Glen H. (1987). Stress and Performance in Diving. Best Publishing Co. San Pedro, CA.

Bea, R.G. (1996). Reliability Based Criteria for Design and Maintenance of Marine Structures. Unpublished course notes for CE290A. University of California, Berkeley.

Bea, R.G. (1994). The Role of Human Error in Design, Construction, and Reliability of Marine Structures (SSC-378). Ship Structures Committee, Washington, DC.

Bea, R.G. (unknown). Human and Organization Factors in the Safety of Offshore Structures. Risk and Reliability in Marine Technology. Carlos Gueded (ed.). Balkema Publishers. Rotterdam, The Netherlands.

Bea, R.G., & Roberts, K.H. (1995). Human and Organization Factors (HOF) in Design, Construction, and Operations of Offshore Platforms. OTC 7738. Offshore Technology Conference. Houston, TX.

Bea, R.G. & Roberts, K.H. (in press). Managing Rapidly Developing Crises: Real-time Prevention of Marine system Accidents. Paper proposed for 16th International Conference on Offshore Mechanics and Arctic Engineering.

Bennett, Peter B. & Monn, Richard E. (1990). Diving Accident Management. Forty-first Undersea and Hyperbaric Medical Society Workshop. Undersea and Hyperbaric Medical Society, Inc. Bethesda, Maryland.

Beyerstein, Gary. (1995). Why do we hurt ourselves? Undersea. Summer 1995.

Boniface, D. E. (1996) Assessing the Risks of and Countermeasures for Human and Organizational Error in the Shipping Industry. Unpublished manuscript, University of California, Berkeley, Department of Naval Architecture and Offshore Engineering.

Brief, Arthur P., Schuler Randall S., & Van Sell, Mary. (1981) Managing Job Stress. Little, Brown & Co., Boston.

Brown, C.V. (1982). Cardiovascular aspects of in-water black-out. In E.H. Lanphier (Ed.), The unconscious diver. Respiratory control and other contributing factors. 30-34. Undersea Medical Society, Inc. Bethesda, MD.

Card, James C., Rear Admiral, U.S. Coast Guard. (1996). Prevention Through People. Surveyor, September 1996, Volume 27, Number 3, 14-15.

Chief of Naval Operations. (unknown). Instruction (OPNAVINST) 5100.19C.

Commander Naval Surface Force, United States Pacific Fleet. (1995). Instruction (COMNAVSURFPACINST) 3501.1D Diving Operational Readiness Assessment (DORA) Program.

Elliott, David H. (1984). Introductory remarks to third session. Philosophical Transactions of the Royal Society of London, Series B, Volume 304, London, UK, Royal Society.

Elliott, David H., M.D. & Bennett, Peter B. (1987) Physiology and Medicine of Diving, 4th ed. Best Publishing. Flagstaff, Arizona.

Flin, R.H. & Slaven, G.M. (1995). Identifying the Right Stuff: Selecting and Training On-Scene Emergency Commanders. Journal of Contingencies and Crisis Management. Volume 3, No. 2, June 1995.

Hee, Derrick. (1996). Basic Minimal Questions for FLAIM II. Unpublished. Marine Technology and Management Group, University of California, Berkeley.

Hee, Derrick, Leverich, Ken & Mathur, Roy. (1996). Table-top exercise to test the proposed FLAIM II methodology. Unpublished exercise results.

Helmreich, Robert L. (1996a). What is CRM? Address to the AQP Working Group, Minneapolis, MN.

Helmreich, R.L. (1996b). NASA/University of Texas/FAA-Funded Aerospace Crew Research Project Website. www.psy.utexas.edu/psy/helmreich/nasaut.htm.

Helmreich, Robert L. (In press). Interpersonal Human Factors in the Operating Theatre.

Helmreich, Robert L., & Merritt, A.C. (1996). Cultural issues in crew resource management. Paper presented at the ICAO Global Human Factors Seminar, Auckland, New Zealand, April 1996.

Helmreich, Robert L., Butler Roy E., Taggart, William R., & Wilhelm, John A. (1995). The NASA/University of Texas/FAA Line/LOS Checklist: A behavioral marker-based checklist for CRM skills assessment. Aerospace Crew Research Project. Technical Paper 94-02.

Human error blamed in jet's downing. (4 November 1996). Navy Times.

Human Error Caused Deadly Air Force Crash. (25 October 1996). San Francisco Chronicle.

McAniff, John J. (1980). U.S. Underwater Diving Fatality Statistics, 1970-78. National Underwater Accident Data Center. Report NOAA Grant No. 4-3-158-31.

McGrath, J.E. (1970). A conceptual formulation for research on stress. In J.E. McGrath (Ed) Social and Psychological Factors in Stress. New York: Holt, Rinehart and Winston, 134-139.

McSween, Terry E. (1995). The Values-Based Safety Process: Improving your safety culture with a behavioral approach. Van Nostand Reinhold. New York.

Merritt, A.C., & Helmreich, R.L. (in press). CRM: I hate it, what is it? (Error, stress, and culture). Paper presented at the Orient Airlines association Air Safety Seminar, Jakarta, Indonesia, April 23-25, 1996.

Mind Garden. (1996). Information Sheet: State-Trait Anxiety Inventory for Adults. Palo Alto, CA.

Morgan, William P. (1995). Anxiety and Panic in Recreational Scuba Divers. Madison: University of Wisconsin, Sport Psychology Laboratory, Department of Kinesiology.

Morgan, William P. (1987). Psychological Characteristics of the Female Diver. Proceedings of the Thirty-Fifth Undersea and Hyperbaric Medical Society Workshop. Bethesda, MD. 21-22 May 1986. UHMS Publication No. 71 (WS-WD). 45-64.

Morgan, William P. (1983a). Psychological Problems Associated with the Wearing of Industrial Respirators: A Review. American Industrial Hygienist Association Journal. 44(9): 671-676.

Morgan, William P. (1983b). Psychometric Correlates of Respiration: A Review. American Industrial Hygienist Association Journal. 44(9): 677-684.

Morgan, William P., Lanphier, Edward H., Raglin, John S., & O'Connor, Patrick J. (1989). Psychological Considerations in the Use of Breathing Apparatus. Proceedings of the Fortieth Undersea and Hyperbaric Medical Society Workshop. UHMS Publication No. 76 (UNDBR). 10/1/89. 111-120.

Perrow, Charles. (1984) Normal Accidents: Living with High-Risk Technologies. Basic Books, Inc., Publishers, New York.

Potter, Patricia A. & Perry, Anne G. (1989). Fundamentals of Nursing: Concepts, Process, and practice. The C.V. Mosby Company, St. Louis.

Reason, J. (1996). The Human Element: A Psychological Perspective. Surveyor, September 1996, Volume 27, Number 3, 18-19.

Reason, J. (1990). Human Error. Cambrige University Press, New York.

Roberts, Karlene H. (1990a). Managing High Reliability Organizations. California Management Review. Summer 1990.

Roberts, K.H. (1990b). Some Characteristics of One Type of High Reliability Organization. Organization Science. Vol. 1, No. 2.

Roberts, Karlene H. (1993). Cultural Characteristics of Reliability Enhancing Organizations. Journal of Managerial Issues. Vol. V Number 2 Summer 1993: 165-181.

Roberts, Karlene H., Stout, Suzanne K., Halpern, Jennifer J.. (1994). Decision Dynamics in Two High Reliability Military Organizations. Management Science. Vol. 40, No. 5, May 1994.

Roberts, K.H., & Libuser, C. (1993) From Bhopal to banking: Organizational design can mitigate risk. Organizational Dynamics, 21, 15-26.

Rochlin, Gene I., LaPorte, Todd R., & Roberts, Karlene H. (1987) The Self-Designing High-Reliability Organization: Aircraft Carrier Flight Operations at Sea. Naval War College Review, 40(4), 76-90.

Shelanski, Samuel. (1996) High Anxiety. SCUBA Diving. May. 32-33.

Spielberger, C.D., R.L. Gorsuch, and R.E. Lushene. (1969). The State-Trait Anxiety Inventory. Palo Alto, CA: Consulting Psychologists Press.

Staff. (1996). Reader Poll Results. SCUBA Diving. May. 32-33.

Taggart, W.R. (in press). The NASA/UT/FAA Line/LOS checklist: Assessing system safety and crew performance. In Proceedings of the Eighth International symposium on Aviation Psychology. Columbus, OH: Ohio State University.

United Airlines. (1996). Command/Leadership/Resource Management.

Vorosmarti, James Jr., MD, (Ed.) (1987), Fitness to Dive. Thirty-fourth Undersea and Hyperbaric Medical Society Workshop. Undersea and Hyperbaric Medical Society, Inc., Bethesda, MD.

Wenk, E., Jr., (1986). Tradeoffs, Imperatives of Choice in a High-Tech World. The John Hopkins University Press, Baltimore, MD.

Wenk, E., Jr., (1996) Presentation. University of California at Berkeley, Ocean Engineering Seminar.